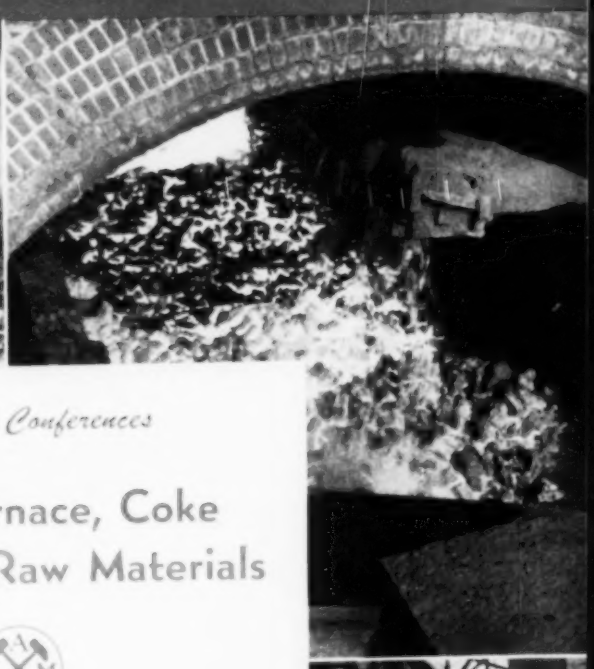
APRIL, 1952

Journal of METALS

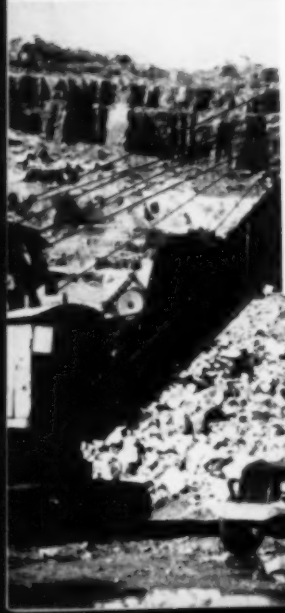


Annual Conferences

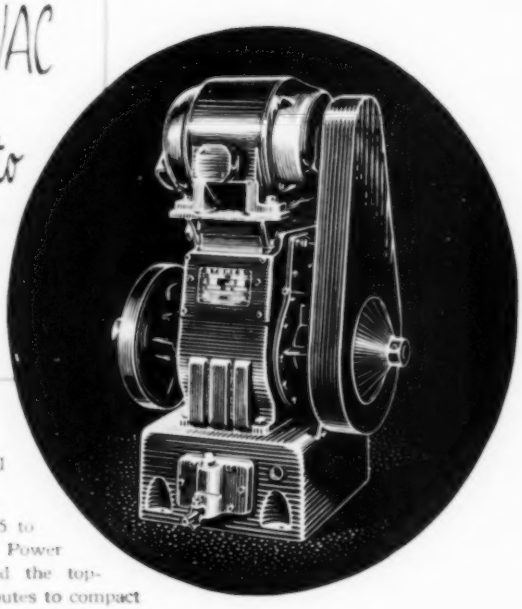
Blast Furnace, Coke Oven and Raw Materials

National Open Hearth Steel Committees

Program Number



STOKES MICROVAC PUMPS...are basic to Vacuum Processing



High volumetric and mechanical efficiency make these famous pumps economical and reliable units in any vacuum system.

Capacities of Stokes Microvac Pumps run from 15 to 500 cfm . . . pressures to 10 microns absolute. Power consumption is low and the top-mounted motor contributes to compact design requiring minimum floor space.

Send for FREE Stokes Vacuum Calculator. This slide rule determines needed pump capacity for any job...shows Centigrade to Fahrenheit conversion. Other useful conversion tables and scales on reverse of rule.

Lubrication of the four moving parts (including the exhaust valve of corrosion-resistant Teflon) is fully automatic. There are no stuffing-boxes or grease fittings, and no packing.

Parts are precision-finished, standard and interchangeable. Freedom from wear assures years of trouble-proof service.

Stokes is the only manufacturer of equipment for complete vacuum systems, including Microvac mechanical pumps, oil diffusion pumps, McLeod Gages and Vacuum Valves.

Consult with Stokes on the application of vacuum to vacuum sintering, melting, de-gassing, heat treating, inert gas purging, vacuum metallizing, and to other applications in which vacuum deserves exploration.

STOKES

STOKES MAKES

Plastics Molding Presses,
Industrial Tabletting and Powder Metal Presses,
Pharmaceutical Equipment,
Vacuum Processing Equipment,
High Vacuum Pumps and Gages,
Special Machinery

F. J. STOKES MACHINE COMPANY, 5516 TABOR ROAD, PHILADELPHIA 20, PA.

Journal of **METALS**

Published to provide a continuing, authoritative, and up-to-date record of technological, engineering, and economic progress in all branches of the metals industry by the
Metals Branch
American Institute of Mining and Metallurgical Engineers, Inc.
29 West 39th Street, New York 18

• • •

JOHN V. BEALL
Manager of Publications

• • •

A. S. COHAN ..... Assistant Editor
D. R. GARRETT ..... Assistant Editor
GRACE RUSSELL ..... Books-for-Review
A. J. SPARKS ..... Asst. Prod. Mgr.

• • •

METALS BRANCH COUNCIL
R. M. Brick ..... Chairman
E. D. Kinkead ..... Secretary
W. A. Dean ..... MD Chairman
K. C. McCutcheon ..... ISD Chairman
T. C. Jones ..... EMD Chairman
T. C. Joseph ..... J. C. Rabbitt
E. D. Parks ..... A. W. Schlechten

EDITORIAL ADVISORY COMMITTEE
H. K. Work ..... Chairman
L. F. Bonetti ..... J. S. Smart, Jr.
W. A. Dean ..... J. C. Kinnear, Jr.
R. D. Pomford ..... Evan Just

TECHNICAL PUBLICATIONS COMMITTEES
J. J. Lauderdale ..... AIME Chairman
M. Semchyshen ..... MD Chairman
A. G. Forrest ..... ISD Chairman
J. Gilbert ..... EMD Chairman
E. J. Kennedy, Jr. ..... Secretary

• • •

JAMES A. STANGARONE
Advertising Manager
B. C. SNELL
Regional Manager, Pittsburgh
1110 McDonald Place, Sewickley, Pa.

• • •

The AIME Publishes:
Journal of Metals
Mining Engineering
Journal of Petroleum Technology

VOL. 4, NO. 4 APRIL, 1952

35TH STEELMAKING CONFERENCE

Blast Furnace, Coke Oven and Raw Materials Conference Program 364
Blast Furnace, Coke Oven and Raw Materials Committees 362
National Open Hearth Steel Conference Program 365
National Open Hearth Steel Committees 363
Open Hearth Committee Local Section Activities 353

NEWS

Journal of Metals Reporter 351
Employment Service 340
Meet the Authors 331
"Drift of Things" 348
Industrial Notes 346
New Products 335
Books for Engineers 342
Coming Events 424
Personals 432
AIME News 422
Pacific Northwest Conference Program 421
AIME Annual Meeting Highlights 426

TECHNICAL FEATURES

Ensley's High Pressure Turbo-Blowers Increase Production, Decrease Coke Rates 369
Manganese: Sources and Beneficiation 377
Conserve Diamond Bort and Cut Hard-To-Machine Materials with New Machining Processes 378

TRANSACTIONS

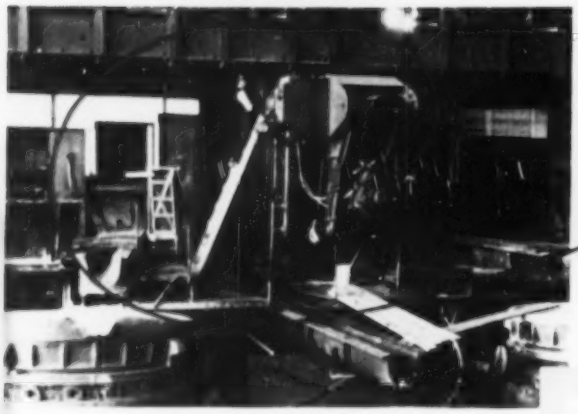
Isothermal Transformation Characteristics of an Iron-Chromium Alloy of Titanium 381
Sintered Titanium Carbide 387
Contribution to the Metal-Carbon-Boron System 391
Lead-Uranium System 397
Viscous Creep of Gold Wires Near the Melting Point 401
Origin of Porosity in Castings of Magnesium-Aluminum and Other Alloys 409

TECHNICAL NOTES

Use of Etch Figures for Micrographic Investigations of Commercially Pure Aluminum and Aluminum Alloys 385
Measurement of Self-Diffusion Coefficients by Autoradiography 407
Magnetic Behavior of Intermediate Phases in Alloys of Transition Elements 420

Published the first day of each month by the American Institute of Mining and Metallurgical Engineers, Inc., 29 West 39th Street, New York 18, N. Y. Telephone: PEnnsylvania 6-9000. Subscription $8 per year for non-AIME members in United States and North, South and Central America; $9 foreign; $6 for AIME members; or $4 additional in combination with a subscription to "Mining Engineering" or "Journal of Petroleum Technology." Single copies, 75 cents; special issues, $1.50. The AIME is not responsible for any statement made or opinion expressed in its publications.
Copyright 1952 by the American Institute of Mining and Metallurgical Engineers, Inc.
Registered cable address, AIME New York. Indexed in Engineering Index, Industrial Arts Index and Chemical Abstracts. Reentered as second-class matter Sept. 21, 1949, at the post office at New York, N. Y., under the Act of March 3, 1879. Additional entry established at Manchester, N. H.

Bailey EQUIPMENT



At the left is shown a Bailey Clay Gun being installed on a large electric furnace. These guns, which have been standard blast furnace equipment for many years, now offer the same unique safety and performance characteristics for electric furnace operations.

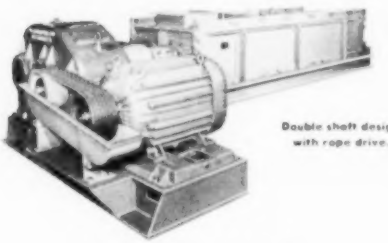
CLAY GUNS

Now . . . Unfailing Performance On

Electric Furnaces

As Well As BLAST FURNACES

The powerful Bailey Clay Gun now is providing best results and safety in plugging tapping holes of large electric furnaces. Thoroughly proved over many years of blast furnace service, this gun has a powerful, motor-driven screw which produces the piston pressure necessary to maintain long and uniform tapping holes. The special Bailey Lever Action forces the gun nose forward with certain accuracy.



Double shaft design with rope drive.

PUG MILLS

FOR SINTERING PLANTS AND BLAST FURNACE DUST CATCHERS

Carefully designed and ruggedly constructed to give dependable, continuous, low-cost service under severe operating conditions. Available are single and double shaft models, with direct, rope or gear drives.

ALSO PRODUCERS OF

- Cinder Notch Stopper
- Blast Furnace Cold Blast Valve
- Blast Furnace Blow-off Valve
- Check and Snort Valves
- Mixer and Check Relief Valve
- Blast Furnace Stove Checker
- Fabricated Steel Stove Bottom
- Precision Table Feeder
- Ladle Skulling Hook
- Check Valve for Cold Blast Main

BRINGS *Safety* AND *Efficiency*

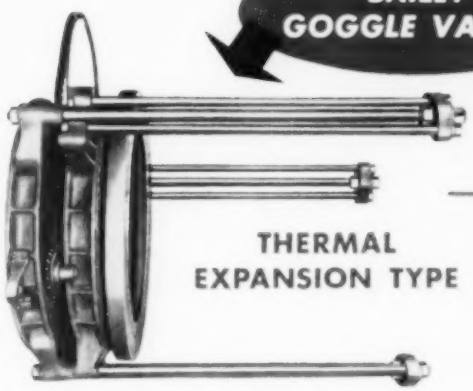
to *STEEL MILL OPERATIONS*

Recognized throughout the iron and steel producing industry for dependability and highest quality, Bailey equipment meets the vigorous requirements of many vital operations. Some of the principal items of Bailey equipment are shown on these pages.

BAILEY GOGGLE VALVES

MECHANICAL TYPE

Bailey Goggle Valves provide a tight, positive seal for shutting off gas mains in emergencies or for repairs. They operate by a powerful clamping force which is applied equally at all points around the disc periphery. Regardless of time between operations, they open or close instantly. Sizes from 6" to 72", totally enclosed if desired.



THERMAL EXPANSION TYPE

The Bailey Thermal Expansion type Goggle Valve is operated by the linear expansion and contraction of the three sets of tubes spaced around the rigid steel flange. When steam is passed into the tubes, thermal expansion of the tubes frees the goggle plate. When the steam is removed, contraction closes the flanges against the goggle plate. Diameters of 36" to 120"

WILLIAM M. **Bailey** COMPANY

ENGINEERS

LEADERSHIP THROUGH QUALITY

1221 BANKSVILLE ROAD **PITTSBURGH 16, PA**

Advertisement

ELECTROMET Data Sheet

A Digest of the Production, Properties, and Uses of Steels and Other Metals

Published by Electro Metallurgical Company, a Division of Union Carbide and Carbon Corporation, 30 East 42nd Street, New York 17, N. Y. • In Canada: Electro Metallurgical Company of Canada, Limited, Welland, Ontario

CHROMIUM...key metal for strength, corrosion resistance, and heat resistance

Chromium is one of the most important alloying elements in iron and steel metallurgy since it markedly improves certain chemical and physical properties.

Increases Strength

The strength of steels is greatly increased by chromium because it retards the transformation of certain constituents during rapid cooling.

This makes it possible to obtain great depth of hardness in high-carbon steels, toughness in structural steel, and high strength and ductility in heavy sections. Chromium also increases resistance to shock by refining the grain of the steel.

Of all the alloying elements, chromium is probably the least expensive for increasing the tensile strength of steel. Additions of as little as 0.25 to 1.25 per cent chromium will increase the yield and hardness

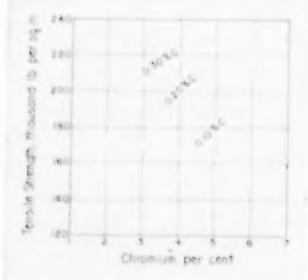


Fig. 1. Chromium increases the tensile strength of annealed steels of varying carbon content.

of the steel, as well as the tensile strength.

In copper, aluminum, and other nonferrous alloys, chromium provides increased strength also.

Imparts Corrosion Resistance

Commercially, chromium is added to steel and iron in amounts up to 80 per cent for the purpose of improving corrosion resistance.

In general, as the chromium content is increased with a given carbon content, the resistance of the steel to corrosive media becomes greater. The well-known stainless steels resist corrosion because substantial percentages, usually 12 per cent or more, of chromium are present.

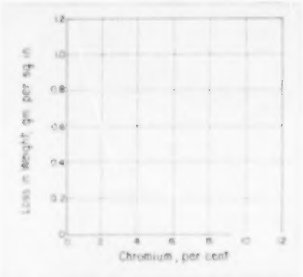


Fig. 2. Results of atmospheric corrosion tests on low-carbon steels at different chromium contents after 10 years of exposure to an industrial atmosphere.

Improves Heat Resistance

In both cast iron and steel, chromium provides good resistance to deterioration from heat. The use of chromium-alloyed iron and steel where high temperatures are encountered, for example, helps to prevent oxidation which would ruin equipment. As little as 1 to 2 per cent chromium is added to cast iron to improve oxidation resistance and reduce growth of grate bars subject to high temperatures. Oxidation resistance improves progressively as the chromium is increased. Steels containing as little as 5 per cent chromium show good life at temperatures up to 1200 deg F. For higher temperatures, appropriate steels of higher chromium content may be selected. Steels containing 25 to 28 per cent chromium give satisfactory service at temperatures up to 2100 deg F.

Alloy cast irons with 15 to 30 per cent chromium are commonly used for applications requiring resistance to severe heat and abrasion.

In non-ferrous alloys, also, chromium is an important constituent for heat and corrosion resistance. It is used in the production of non-ferrous metal-cutting tools, chromium bronzes, and electrical resistance alloys.

Available Alloys

Chromium is produced by ELECTROMET in the forms listed below which are suitable for every use of the iron, steel, and non-ferrous metal industry.

"EM," "Electromet," and "SM" are trade-marks of Union Carbide and Carbon Corporation.

Alloys of Chromium and Their Uses

Low Carbon Ferrochrome	For production of corrosion- and heat-resistant steels, commonly known as the "stainless steels," as well as special high-temperature alloys in which a low carbon content is desirable.
High Carbon Ferrochrome	For production of chromium-bearing steels that do not require low percentages of carbon. Also used for adding chromium to cast iron.
Nitrogen-Bearing Ferrochrome	For reducing grain size and improving physical properties of high-chromium steels.
"EM" Ferrochrome-Silicon	Used in the production of stainless steels for adding chromium to the bath, and for reducing oxidized metals in the slag back into the bath.
"EM" Ferrosilicon-Chrome	Readily soluble material for making either furnace or ladle additions of chromium to steels.
"SM" Ferrochrome	Readily soluble material for making chromium additions to steel or cast iron in either the furnace or the ladle.
Foundry Ferrochrome	Especially for use in making readily soluble ladle additions of chromium to improve composition and properties of cast iron.
Chromium Metal	For use in non-ferrous chromium-bearing alloys, such as electrical resistance alloys, high-temperature and corrosion-resistant alloys, metal-cutting tools, chromium bronzes, and certain high-strength aluminum alloys.
"EM" Chromium Briquets	For adding chromium to cast iron in the cupola.

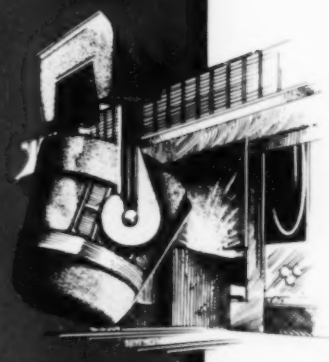
Quality

REFRACTORIES

★ BLAST FURNACE REFRACTORIES

★ OPEN HEARTH REFRACTORIES

★ ELECTRIC FURNACE REFRACTORIES



★ HEATING FURNACE REFRACTORIES

★ REFRACTORY MORTARS • PLASTICS CASTABLES

NARCO

NORTH AMERICAN REFRACTORIES CO.

1013 National City—E. 6th Bldg. • Cleveland 14, Ohio

New York · Boston · Pittsburgh · Detroit
Philadelphia · Buffalo · Chicago · Cleveland

NORTH AMERICAN REFRACTORIES, LTD.

141 Wanless Avenue, South • Hamilton, Ontario, Canada

HIGHEST RESOLUTION for Every Magnification

Plus- WIDEST SELECTION of Resolving Powers

	OBJECTIVES						EYEPIECES			Approx. Bellows Draw, in
Photomicrographic Mag.	Achromatic		Fluorite		Apochromatic		Mag.	Huygh.	Amp.	
	Mag.	N.A.	Mag.	N.A.	Mag.	N.A.				

Meet The Authors

J. J. Shannon (p. 369) a native of Birmingham, attended the University of Alabama and Cornell (B.S. mechanical engineering). He was first employed as a chemist at the Ensley works, Tennessee Coal, Iron & R.R. Co. He has subsequently been with the metallurgical dept., Fairfield steel, Fairfield structural mill, and tin mill. In 1929 Mr. Shannon was appointed assistant superintendent of blast furnaces at Fairfield and in 1950 was made superintendent of blast furnaces at Ensley. Presently residing in Birmingham, his hobby is fishing.

Charles W. Phillips (p. 381) born in Chicago, attended the University of Wisconsin (B.S. Met. Eng.) and University of Michigan (M.S. Met. Eng.). Mr. Phillips joined Dow Chemical Co. as research metallurgist in magnesium technology in 1942. He has been a faculty member of the University of Michigan since 1947. Color photography, bridge, and house plant culture are the hobbies of this AIME member.

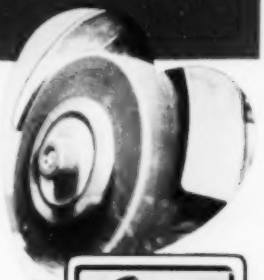
Donald N. Frey (p. 381) manager of the metallurgical dept., scientific laboratory, Ford Motor Co., Detroit, was born at St. Louis. He earned his B.S. from Michigan State and Ph.D. Met. E. from the University of Michigan. During World War II, Dr. Frey was in the Army and following his discharge was at the University of Michigan. He became an instructor in 1949 and was made an assistant professor in 1950. A member of the Detroit Section, AIME, he also holds membership in the ASME, ASM, and American Ceramic Society. He has authored a previous paper: *Fundamental Effects of Cold Working on Creep Resistance of An Austenitic Alloy*. His four children take up most of his spare time.

R. J. Teitel (p. 397) comes from Indianapolis and attended Purdue University (B.S. Met. E.) and Massachusetts Institute of Technology (Sc.D. Met. E.). Now with the Brookhaven National Laboratory as an associate metallurgist, he was engaged on the Manhattan Project in 1944 at Decatur, Ill. For one year he was at Armour Research Foundation and in 1945 was again associated with the Manhattan Project at MIT. This AIME member has presented the paper *Beryllium-Iron System*.

E. J. Whittenberger (p. 408) research metallurgist with the Aluminum Co. of America was born at Youngstown. He holds B.Met.E. and M.Sc. degrees, and is presently studying for a D.Sc. at Carnegie Institute of Technology. In 1942 he was a metallurgical observer for Carnegie-Illinois Steel Corp. During World War II, Mr. Whittenberger was in the Navy attached to the Pacific fleet. He attended Carnegie Tech Graduate School as an Alcoa fellow and joined Alcoa in 1950. A member of the Cleveland Section, AIME, he enjoys hunting, fishing, and photography.

YOUNG *Electro* HEARTS

FOR YOUR OLDER GRINDING MACHINES



If you are a victim of the machine tool situation, you'll find that Electro *Specific Purpose* Grinding Wheels in your older machines, will largely offset obsolescence.

The heart of any grinding machine is the wheel; and super-efficient wheels can help you get by until the machine tool situation eases.

The technicians in our chemical and engineering laboratories will, if necessary, originate special wheels to meet your requirements.

They have complete latitude as to kinds of abrasives and types of bonds. We'd like to apply this total freedom in materials and methods for gains to you in quality of output, saving in time and lower costs.

May we, at our risk, send a Field Engineer to consult with you within the next few days?

Electro Refractories & Abrasives Corporation
344 Delaware Avenue, Buffalo 2, N. Y.
Regional Warehouse: Los Angeles 58, California
Plants: Buffalo, N. Y. and Cap-de-la-Madeleine, P. Q., Canada

Electro SINCE 1910

SPECIFIC PURPOSE
GRINDING WHEELS
for
CUTTING OFF
•
PRECISION GRINDING
•
SNAGGING
•
MANUAL 645 AND SPEED CALCULATOR FREE ON REQUEST

Electro SPECIFIC PURPOSE GRINDING WHEELS

Johnston Cinder Pots, with curved sidewalls, are built so that there is no distortion in the critical heat zone—the middle third of the pot. Left pot is 400 cu. ft. capacity, right pot, 75 cu. ft.

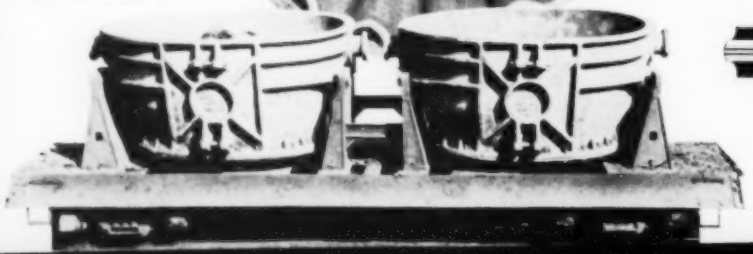
Johnston Cinder Pots

decrease slag disposal costs

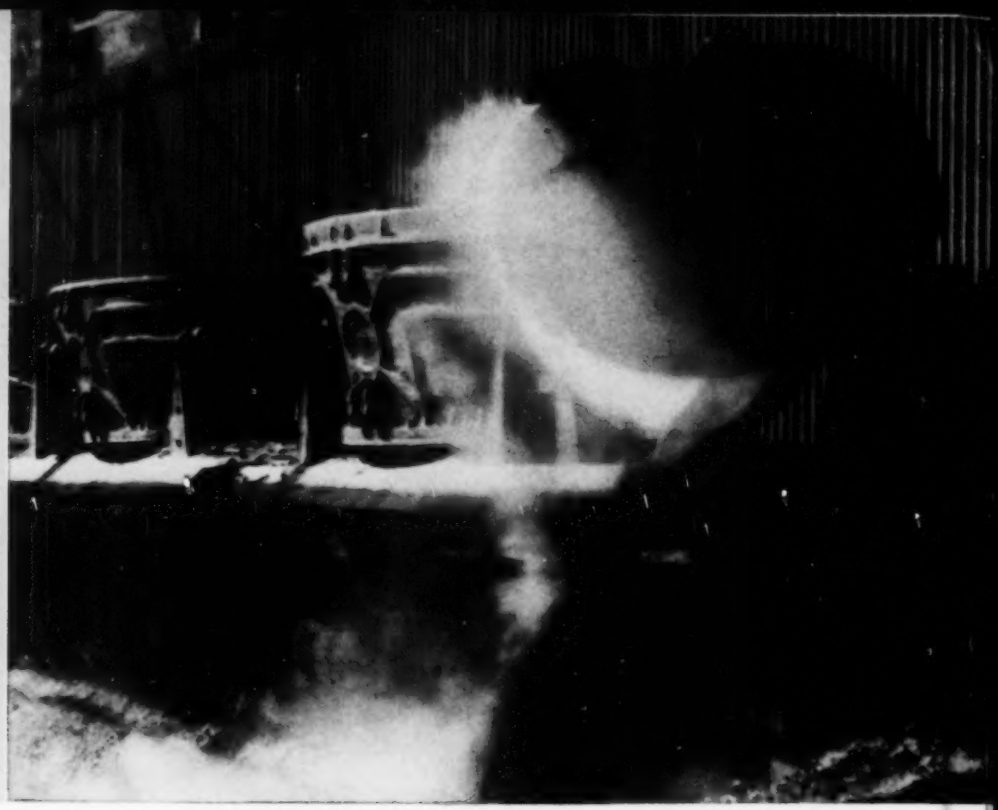
The long, useful life of Johnston Cinder Pots results from long application experience.

Corrugations provide maximum cooling surface area, help discharge skull without rapping.

Two 425 cu. ft. capacity oblong Johnston Cinder Pots mounted on dingey.



MACKINTOSH HEMPHILL COMPANY
PITTSBURGH, U.S.A.



. . . because JOHNSTON CINDER POTS are engineered for increased heat-hours of service and faster turn-around time!

Performance records for Johnston Cinder Pots have been established in blast furnace and open hearth operations throughout the country, because Johnston Pots are designed for each job by experienced engineers. Here are two examples of how this engineering constantly improved Johnston Cinder Pot performance:

JOHNSTON CORRUGATED POTS with the expansible rim (100 cu. ft.) averaged 3,500 round trips in actual practice, against the expected 1,000 round trips at one plant.

MODERN, OBLONG, FLAT-BOTTOM POTS (designed to utilize existing tunnels) resulted in a 100% increase of capacity over older type pots.

FEATURES OF JOHNSTON CINDER POTS INCLUDE:

1. Expansible rims allow pots to retain shape under severe service conditions.
2. Corrugated walls permit rapid heat dissipation, and help eliminate firecracking and wall checking.
3. Patented construction prevents wall sag in slag-filled pots.
4. Johnston Pots are repairable if damaged in service.

For maximum service, for minimum costs of slag disposal, check with Mack-Hemp. Johnston Slag Handling Equipment Specialists have had much experience in the design and production of Cinder Pots, a valuable background of information you'll find most useful. To keep up with the latest developments in Johnston Cinder Pots, watch what's new at Mack-Hemp.

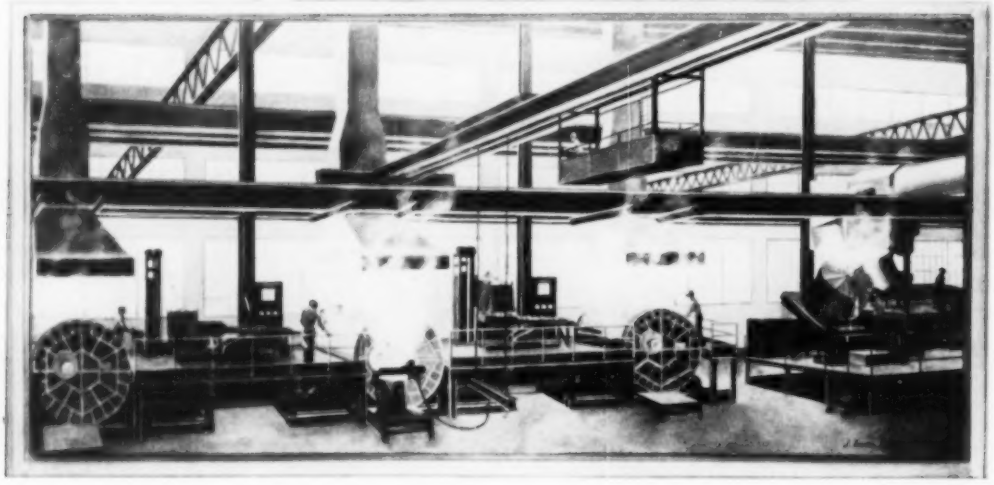
MACKINTOSH-HEMPHILL

COMPANY

PITTSBURGH & MIDLAND, PA.

MACKINTOSH-HEMPHILL PRODUCTS INCLUDE: rolls . . . steel and special alloy castings . . . completely integrated strip mills . . . heavy duty engine lathes . . . Mackintosh-Hemphill rotary straighteners . . . improved Johnston patented corrugated cinder pots and slag-handling equipment . . . shape straighteners . . . end-thrust bearings . . . shears . . . levellers.

AJAX Induction Melting Furnaces- A Modern Tool for Industry



This oil painting, 9 feet long in full color, by J. Gordon White, shows AJAX-SCOMET installation at Scovill Manufacturing Company, Waterbury, Connecticut.

Here is a new tool for melting metal . . . Something that can concentrate enormous power in a small space . . . Something that can be adapted to accurate pouring, to precise temperature control, to inert gas protection, to high grade refractories . . . A tool that can be used for all existing non-ferrous metals and alloys.

AJAX furnaces paved the way for continuous casting processes which lay dormant in old patents of farsighted inventors who thought ahead of their times. Junghans, with the help of the AJAX furnace, developed his continuous casting process at the Wieland Works in Germany before the last World War.

Scovill perfected the Junghans process in this country and is using AJAX-SCOMET furnaces of unprecedented size for melting, as shown in painting above. Nichols Wire & Aluminum Company used the first commercial Properzi machine for continuous production of aluminum wire from molten metal delivered by AJAX furnaces; U. S. Metals Refining Company is using AJAX-SCOMET furnaces for continuous casting of oxygen-free copper. Cleveland Graphite Bronze Company produce their famous stock for steel backed copper-lead bearings exclusively in AJAX melting furnaces. AJAX furnaces are used in many plants and research laboratories for continuous bonding aluminum to steel.

AJAX made the first furnace for galvanizing steel in a refractory lining with accurate temperature control. AJAX furnaces were instrumental in the realization of modern squirrel-cage aluminum rotor production. AJAX supplied the first commercial automatic pouring device for die-casting machines.

These few examples show how AJAX induction furnaces can be applied to modern manufacturing methods. Write us for further information.

AJAX
TAMA-WYATT

AJAX ENGINEERING CORP., TRENTON 7, N. J.

INDUCTION MELTING FURNACE

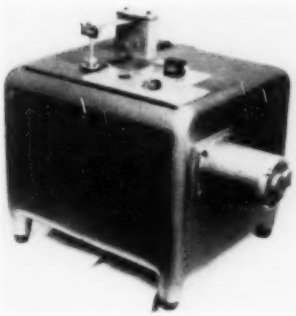
AJAX ELECTRO METALLURGICAL CORP., and Associated Companies
AJAX ELECTROTHERMIC CORP.,
AJAX ELECTRIC CO., INC.,
AJAX ELECTRIC FURNACE CORP.,

New Products

New Products | New Literature | New Services

For Further Information or Literature on any Product, Fill in the Coupon and Send to JOURNAL OF METALS. Students are Requested to Apply Directly to Manufacturers for Bulletins and Information.

1—FATIGUE MACHINE: A new model machine has been announced by *Baldwin-Lima-Hamilton Corp.* The SF-2 is a table model, the smallest of five standard models ranging in alternating force capacity from 25 to 10,000 lb or from 50 to 20,000 lb in one direction only. Maximum travel



of the loading yoke is ½ in. and testing speed is 1800 cycles per min. The SF-2 is driven by a ¼ hp synchronous motor, has a dial load indicator that is graduated in 0.125 lb increments, and a cycle counter. Overall dimensions are 19¼ in. wide x 25 in. long x 21¾ in. high.

2—RUSTCLEAN: A new chemical treatment that removes rust, tarnish, and light oil, chemically prepares metals for paint and retards corrosion, is available from *Octagon Process, Inc.* It chemically cleans the surface of steel, iron, aluminum, zinc, and cadmium, and forms a phosphate coating which acts as a base for organic finishes.

3—BURETTE: A burette unit featuring a plastic reservoir that requires only a squeeze to fill an automatic self-leveling burette is obtainable from *Hagan Corp.* These units are available in 25 ml and 10 ml sizes graduated in tenths of a ml. There is a special base that holds the plastic bottle and provides a stable platform for beaker, flask, or dish.

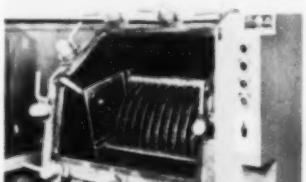
4—CLAMP: Case hardened unit, combining features and strength of a standard drop forged C clamp and a toolmaker's parallel, has been introduced by *Centinela Industrial Supply Co.* Three different gripping faces are built into the clamp to accommodate all types of holding jobs. It is available in 1½, 3, 6, 9, and 12 in. The trunion absorbs vibration insuring a firm grip throughout milling, routing, and shaping operations.

5—CHAMFERING ELECTRODE: Electrode designed for gouging, chamfering, and partial milling operations on any metal or alloy has been announced by *Eutectic Welding Alloys.* It features a heavy coating that forms a cone at the striking end of the electrode, providing a natural jet effect arc.

6—PAINT BOOTH CONDITIONER: A conditioning agent for industrial paint spray booths has been developed by the *Pennsylvania Salt Mfg. Co.* The product is used in the water circulating system and is designed to prevent adhesion of paint to the curtain wall and to assist the water cascade in preventing escape of paint into the atmosphere. Pennsalt PB-1 is a highly alkaline, anhydrous, free flowing, dust free material containing nonfoaming agents. It is packaged in 400 lb drums.

7—MAGNETIC CHUCKS: Built by *Viking Industries*, two small sized magnetic chucks concentrate deep magnetic holding power and speed precision grinding of small workpieces. The units operate equally well in either horizontal, angular, or vertical plane. Operation is from 6-v dc rectified from standard ac.

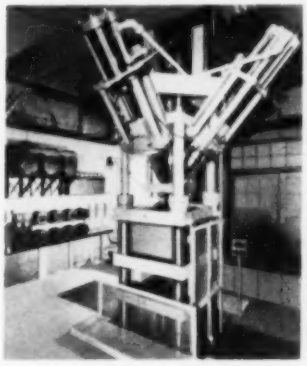
8—FINISHING MACHINE: An addition to the line of mechanical finishing machines has been announced by the *Roto-Finish Co.* Model DW-30-36-ISF is designed especially to effectively finish disc type circular parts. The machine is the stationary fixture type and uses directional flow of finishing media. It has a sin-



gle 30⅛x35¼ in. ID rubber lined compartment with an 18 cu ft capacity. An automatic timer controls the operation from 0 to 20 hr without attention by the operator. A variable speed power unit with a remote control handle enables the operator to vary the speed of the cylinder from 10 to 30 rpm.

9—WET ABRASIVE BLASTING: With precision close tolerance cleaning process, using fine mesh abrasives, it is possible to clean work having sharp edges, and corners. Liquamatte is a product of the *American Wheelabrator & Equipment Corp.*

10—PLASTIC INJECTION: A vertical molding machine designed and developed by *Worcester Moulded Plastics Co.* permits the molding of pieces in large sizes never before



possible. Four preplasticizing units preheat the plastic material to give greater flowing properties. Battery cases, refrigerator parts, lighting fixtures, etc. can be manufactured by plastic injection molding.

11—METALLOGRAPH: A desk-type metallograph permitting microscopic study of metals under polarized light as well as phase and bright field illumination is available from *American Optical Co.* It has an automatic, motor-driven arc lamp, built-in illuminator, and four built-in photographic eyepieces that operate in quick change slide.

12—ELECTRONIC PILOT RELAY: Capable of controlling large values of current and power with a current flow of 0.000002 amp through the utilization of a cold cathode tube, this electronic pilot relay is available from *Haledy Electronics Co.* The relay will operate over any input resistance from a dead short to 10 megohms. It utilizes a 115 v 60 cycle line source and consumes 2 w when in operation.

13—MILLING MACHINE: New model has been announced by *Diamond Machine Tool Co.* It has a longitudinal travel of 14 in., maximum vertical travel from center of spindle to table top 15 in., and cross traverse of 5½ in. The full table working surface is 5¾x24 in.

14—PLASTISOLS: Production of a line of plastisols and organosols has been started by *Houghton Laboratories, Inc.* They are used as coatings for coils, transmission belting, electroplating racks and tanks.

15—FABRICATING UNIT: A slotted leg, galvanized steel angle designed for all purpose industrial fabrication has been announced by the *Acme Steel Co.* The lengthwise rows of slots, 10 ft long, 3x1.5x0.060 in., permit rapid assembly by bolting of shelving, bins, motor and machinery mounts, assembly tables, conveyor line structures, and other plant equipment.

16—PLIER SNIP: Originally designed for use in electronic and incandescent lamp manufacture, these pliers are finding a wide range of application wherever fine wire cutting or thin metal snipping is necessary. They are drop forged for toughness, the cutting edges are hand honed, and have an extended throat for greater reach in cramped quarters without reduction in leverage. *Utica Drop Forge & Tool Corp.*

17—BENDING MACHINE: Capable of cold stretchforming a variety of structurals and sheet metal parts which conventionally are hot-formed, this roller table bending machine has been developed by *Strothers Wells Corp.* It will stretch-form metal up to 2½ sq in. area. The machine is powered from a controlled hydraulic mechanism and set up for completely automatic operation.

18—DY/CHEK FORMULA: A new non-toxic formula has been announced by *Turco Products, Inc.* This dye penetrant inspection process can be used on both ferrous and nonferrous metals, and can be applied by either spraying, dipping, or brushing.

19—ASBESTOS FIBERS: New equipment makes available fibers to meet specifications for specific industrial requirements in groups four and five. Some of the grades follow standard Canadian classifications. Test samples will be sent upon request. *Charles Abbott & Associates, Inc.*

Free Literature

20—POWER UNIT: Catalog 400 issued by *Rivett Lathe & Grinder, Inc.*, describes hydraulic power units in single, double, and combination pump types. Working drawings and specifications, maximum pressures at a given hp, and hp requirements at given pressures are included.

21—SPECIMEN MOUNT PRESS: *Buehler Ltd.* has issued bulletin describing AB speed press. Features include use of preheated premolds, rapid closing and universal application for thermosetting of thermoplastic materials in 3 sizes.

22—MAGNETS: A listing of sizes and shapes of Carboloy Alnico permanent magnets is included in bulletin PM-100 available from Carboloy dept., *General Electric Co.* The illustrated catalog contains pull curve and size information in tabular form on stocked types of cast and sintered permanent magnets.

23—THERMOHMS: Resistance thermometers that are used to detect temperatures between −325° and +1000° F with accuracies from ±0.018° to ±3.0° F are fully described in catalog issued by *Leeds & Northrup Co.* Accessories and replacement parts are grouped with the related thermohms.

24—CORROSITE: A corrosion resistant protective plastic paint is described in bulletin available from the *Corrosite Corp.* It explains systems for painting metals, concrete, stone, brick, plaster, and asbestos board.

25—HOT-DIP GALVANIZING: Reprint giving galvanizing cycle information including acid concentrations, temperatures, and immersion times is offered by the *Hanson-Van Winkle-Munning Corp.* Detailed information is included on the zinc ammonium chloride type of flux into which work is immersed following rinsing operation.

26—CARBIDES: Standard and special cemented tungsten carbides are listed in catalog issued by *Greenleaf Corp.* Complete information is provided on standard blanks, carbide milling data, cutting and grinding data and other useful facts.

27—LOW-TEMPERATURE RESEARCH: An informal presentation of current activities in low temperature and electromagnetic research is given in pamphlet obtainable from *Arthur D. Little, Inc.* Those interested in low temperature research, particularly in the liquid helium temperature range, will find this pamphlet interesting.

28—JIGS AND FIXTURES: Catalog published by the *Jergens Tool Specialty Co.* illustrates the complete line of mass-produced jig and fixture components. Lever knobs, clamp assemblies, chuck jaw blanks, and sine fixture keys are described.

29—SPECIMEN GRINDERS: Six-page booklet describing grinders and surfacers designed for metallurgical samples. Both belt and wheel types are offered for wet or dry grinding. *Buehler Ltd.*

30—TESTING MACHINES: Catalog on hydraulic Universal testing machines has been issued by Riehle Testing Machines Div., *American Machine & Metals, Inc.* Illustrations, specifications, and operating details on machines with capacities up through 400,000 lb are given.

31—MACHINERY PARTS: Cast and wrought alloy parts used in industry to solve abrasion, corrosion, and high temperature problems are illustrated in booklet obtainable from *Haynes Stellite Co.* Blueprints, and tables, are also contained.

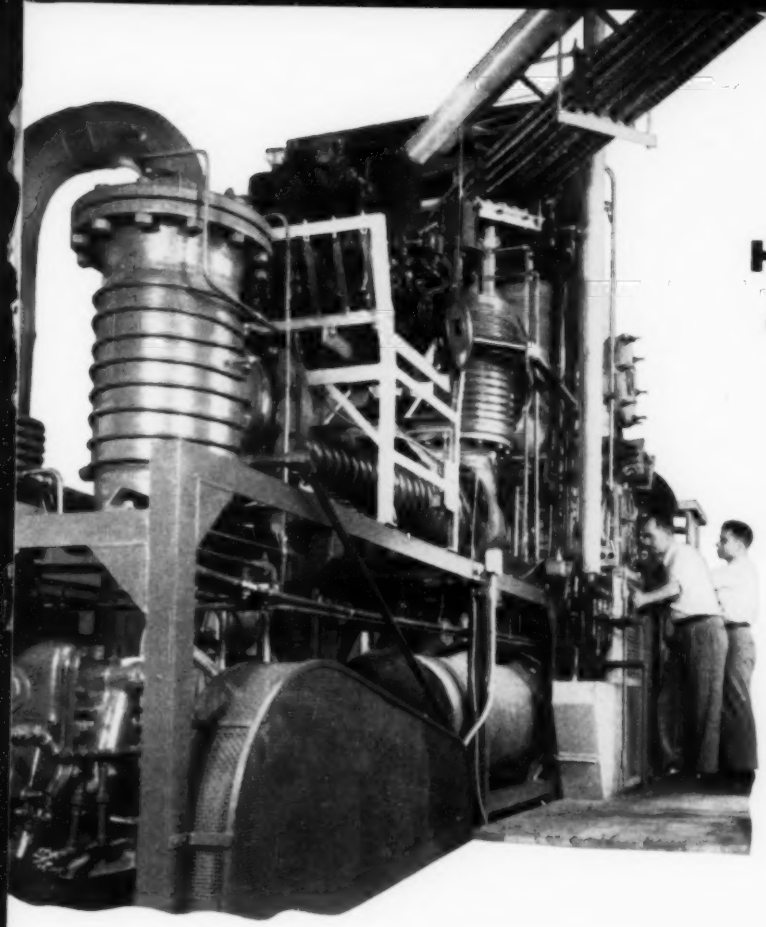
Journal of Metals — April
29 West 39th St.
New York 18, N. Y.

Please send me { More Information ☐ / Free Literature ☐ / Price Data ☐ } on items indicated

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30

Students are requested to write direct to the manufacturer.

Name _____ Title _____
Company _____
Street _____
City and Zone _____ State _____



High vacuum develops muscles for "moly"

Pure molybdenum is sensitive to oxygen at the temperature it takes to melt it . . . and "moly" with oxygen is not much use. Jet engines, rockets, and other equipment need the pure metal because it stands up under heat that melts the strongest steels, but if there's oxygen in it the advantage vanishes.

High vacuum solves the problem. Climax Molybdenum Company of Detroit, Michigan, hydraulically compresses pure molybdenum powder and sometimes molybdenum chips with a little carbon. This mass is sintered into a crude stick which serves as a consumable electrode in an arc. The molten metal is caught in a pool which serves as the other electrode while it builds up into a half-ton ingot of malleable, ductile molybdenum.

The molybdenum turns out malleable and ductile because *high vacuum* gets rid of the injurious oxygen.

Why, you may ask, don't they just use an inert gas? Bear in mind that at the high vacuum under which these operations are carried out (20 microns Hg) oxygen content is equivalent to about 0.0026% at atmospheric pressure. Inert gas pure enough and in sufficient quantity to dilute atmospheric oxygen to this level would be staggering in cost. A DPi oil ejector pump, uniquely economical to operate, creates the vacuum in the sizable space needed for the whole series of continuous operations and gets rid of the gases evolved.

In supplying equipment for high vacuum metallurgy, DPi pools its own diversified experience in high vacuum technology with the experience of leading manufacturers of metallurgical furnaces.

In many other fields, too, where high vacuum processing has earned a useful role, DPi stands ready to help you with the vital details that add up to efficient, profitable production. Write to ***Distillation Products Industries,*** Vacuum Equipment Department, 607 Ridge Road West, Rochester 3, N. Y. (Division of Eastman Kodak Company).

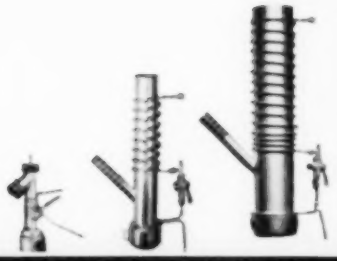
DPi

high vacuum research and engineering

Also . . . vitamins A and E . . . distilled monoglycerides . . . more than 3500 Eastman Organic Chemicals for science and industry

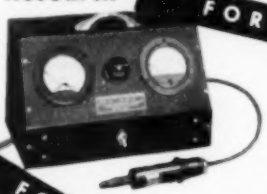
When Working with High Vacuum

Select the equipment to fit the job from the complete line of National Research Vacuum Equipment



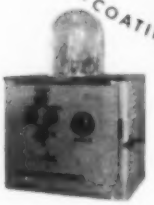
FOR CREATING

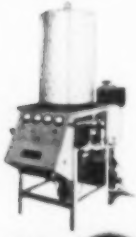
FOR CONTROLLING

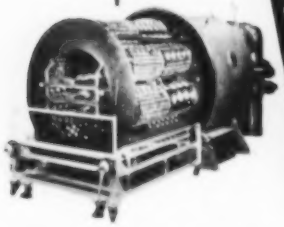


FOR MEASURING HIGH VACUUM

FOR VACUUM COATING

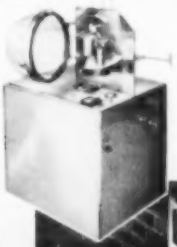


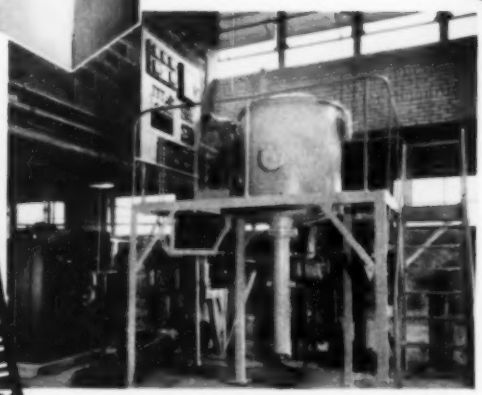


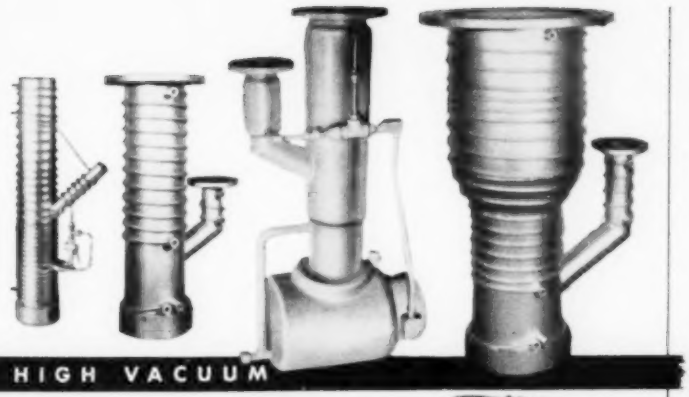


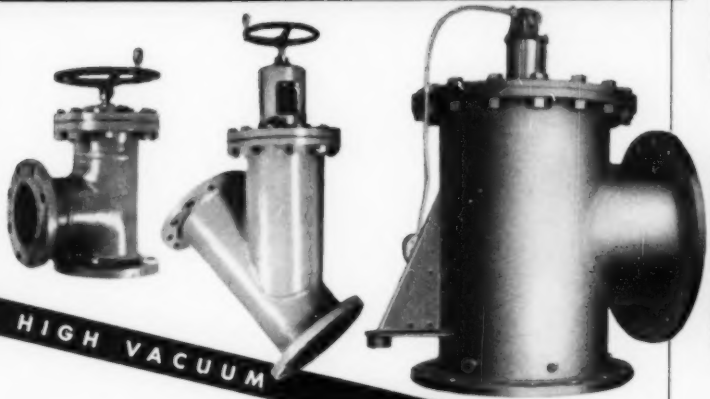
FOR PROCESSING IN HIGH VACUUM

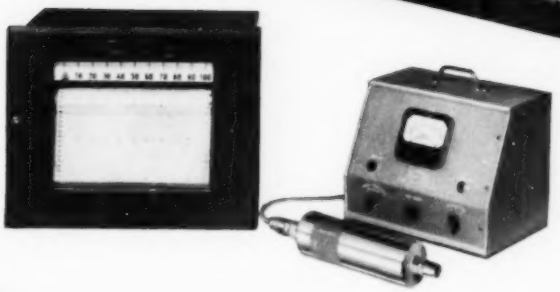
FOR METALS



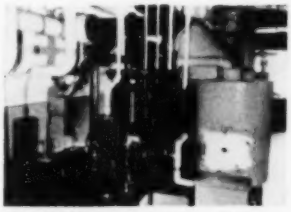




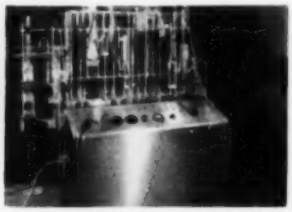




Special Equipment and Plant Installations



V25D Rotary Condenser. A typical processing unit in a large, high vacuum plant which we designed and built.



Vacuum Fusion Gas Analyzer. Analyzes metals and alloys, including titanium, for combined or dissolved oxygen, nitrogen, and hydrogen.

This is only a part of the complete line of National Research equipment. Our equipment is designed to fulfill practical performance requirements of vacuum equipment users.

Gain the benefits of the high standards of practical performance built into all National Research products. Write us for further details.

National Research Corporation

Equipment Division

SEVENTY MEMORIAL DRIVE, CAMBRIDGE, MASSACHUSETTS

Personnel Service

New York 18 Detroit
San Francisco
Chicago 1

POSITIONS OPEN

Engineers. (a) Welding engineer, 25 to 35, M.E. or E.E., to promote automatic arc welding equipment and processes. Actual welding experience required. Knowledge of automatic gas cutting machines helpful. Experience in manufacturing or heat treating of metals desirable. Extensive travel, short trips. Work out of New York for the present. Good speaker along technical lines, ability to write reports. Actual shop demonstrations of equipment. Salary, $6000 to $6600 a year plus travel expenses. (b) Metallurgical process engineer, 30 to 45, metallurgical or chemical degree, with at least five years' metal refining experience, preferably steel. Capable of speaking to technical men and writing concise reports on basis of findings. Liaison between customers, field men, and research laboratory. Help flow of ideas among these people. Capable of demonstrating carbide desulphurization of metals under actual shop conditions. Work out of New York for present, relocate Chicago or Pittsburgh area in one year. Salary, $6600 to $7200 a year plus travel expenses. Y6734.

Control Metallurgist with some experience in induction melting of stainless and high temperature alloys, to be responsible for incoming and outgoing materials, inspection and pouring. Location, Ohio. Y6463.

Sales Engineer, 26 to 33, mechanical, chemical or metallurgical engineer, with process industry experience, to sell drying and cooling equipment in eastern territory, to food, chemical, metallurgical and process industries. Salary, $3900 to $5400 a year plus bonus. Headquarters, New York. Y6707.

Plant Foreman, chemical, mechanical or metallurgical engineer, with acid or chemical plant experience. Salary, $5220 a year. Y6652(a).

Welding Engineer, 28 to 40, graduate, with knowledge of metallurgy, strength of materials and welding principles. Minimum five years' shop and engineering experience in arc, inert gas, and resistance welding, preferably on heavy machinery and sheet metal products. Analyze stresses in welded structures, write welding specifications and tests, advise on proper heat treatment, and give instructions on good welding practices. Salary, $5500 to $6500 a year. Y6650(c).

Metallurgist, recent graduate preferred, who is interested in gaining experience in the manufacture of steel, wire and wire products. Location, northern New Jersey. Y6628.

Production Manager, 35 to 45, with considerable experience on direct line production for metal forming, plant layout, scheduling, and costs. Salary, $10,000 to $12,000 a year. Location, southern New Jersey. Y6618.

Junior Sales Engineer, 26 to 35, with chemical engineering, metallurgy, or mechanical engineering training, and some experience in industrial sales, and/or chemical plant operating experience, to sell corrosion service valves to chemical, petroleum, etc., industrial and engineering companies. Will receive factory and field training and probably be assigned to New York district office. Some traveling and willing to relocate if necessary. Salary, $3600 to $4800 a year plus bonus. Company furnishes car, and pays all traveling expenses. Location, New York. Y6613.

Engineers. (a) Mill metallurgist, preferably with previous plant experience, as well as experience in testing laboratories. Should be capable of carrying out ore beneficiation tests and research work, and making reports on the results obtained. Work will be in the nature of laboratory testing, gravity concentration, flotation concentration and cyanidation, and some roasting tests. Salary, $4200 to $4800 a year depending upon qualifications. Room and board and transportation, if single; and if married, furnished house, plus $75 a month board allowance after three months single status. (b) Junior mill metallurgist with some laboratory experience, with knowledge of the technique to carry out assigned tasks with supervision. Salary, $3000 to $3300 a year, plus board allowance, etc. Location, Central America. Y6573.

Metallurgist, experienced in ore dressing, including flotation. Work largely on special ore testing problems in eastern states. Salary open. Y6572(c).

Metallurgical Engineer, technical graduate, with metallurgical background or experience, for electrolytic copper refinery. Opportunity for supervisory work in operating departments. Salary open. Location, Texas. Y6565.

Chemist-Metallurgist, 25 to 35, for work in nonferrous metal plant. Location, Brooklyn. Y6535.

Sales Engineer, under 40, metallurgical graduate, with nonferrous metallurgical experience, to sell continuous casting brasses, bronzes, bearings and bushings. Salary, $4800 a year. Territory, Midwest. Headquarters, Indiana. Y6529-CD.

Junior Metallurgist, metallurgical engineer, electrochemist or chemical engineer, to conduct research on metallurgical problems assigned, apply basic principles such as chemistry, physics, and mathematics to work performed, develop reports and perform other work functionally required. Salary, $3900 to $4900 a year. Location, New Jersey. Y6524.

FOR SALE

Zeiss Neophot Metallograph (horizontal), modified.

Kennametal Inc.
Latrobe, Pa.
Attention: A. D. Stevens, Metallurgist

PHYSICAL METALLURGIST

Experienced Ph.D. or equivalent, interested in wide variety petroleum metallurgical problems. Leading Midwest research organization.

BOX C-6, JOURNAL OF METALS

Metallurgical or Mechanical Engineer — Large Eastern metal-producing company has excellent opening for technical service and development work in hot and cold fabrication of nonferrous alloys. Knowledge of design desirable. State age, education and experience.

Box C-8, JOURNAL OF METALS

SALESMAN. Applicant must have proven experience in the sale of nonferrous metals. Metallurgical degree or equivalent knowledge helpful. Adaptability to our technical and sales policies will be necessary. Prefer applicant between 25-35 years. Willing to travel. A complete resume of education and work record, including a recent photograph, is requested. Location: Great Lakes area.

Box C-9, JOURNAL OF METALS

MEN AVAILABLE

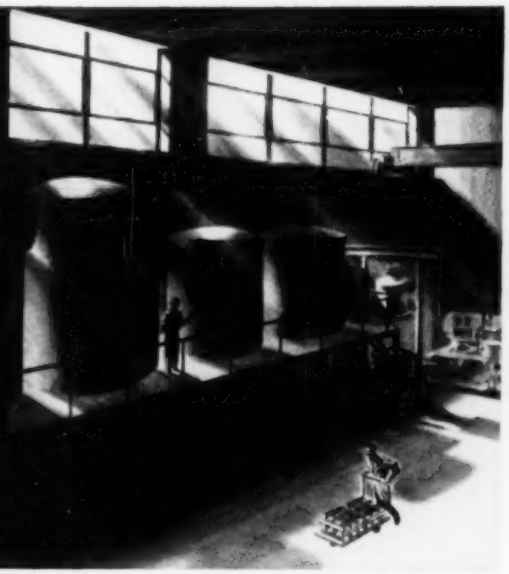
Extractive Metallurgist, recent graduate, M.S. in extractive metallurgy, desires to work in nonferrous field. Age 26. Any location in U.S.A. Noncitizen. M-675.

National Research Corporation

Announces

the formation of VACUUM METALS CORPORATION

U. S. A.'s Sole Commercial Source of Vacuum Melted Metals



Vacuum Metals Corporation has been formed to supply specialty metals and alloys for applications of high performance in terms of physical, chemical or electrical properties.

Vacuum melting techniques developed by National Research are used to produce metals of higher purity and alloys held to closer composition tolerances than ever before achieved commercially.

Organized by National Research as a wholly-owned subsidiary, Vacuum Metals Corporation now has facilities for vacuum melting more than five tons per day of metals such as copper, nickel, molybdenum or iron.

The unique properties of vacuum melted pure metals and alloys are particularly useful in applications such as electronic and electrical parts, magnetic materials, bearing materials, diaphragms, instrument components, laboratory standards and Atomic Energy projects.

Write to us for further information about our facilities.

VACUUM METALS CORPORATION

Subsidiary of National Research Corporation

70 MEMORIAL DRIVE · CAMBRIDGE 42, MASSACHUSETTS

HIGH PURITY METALS · HIGH VACUUM CASTING · SPECIAL ALLOYS · GP (Gas Free) METALS

Books for Engineers

Theory of Electromagnetic Waves, a symposium June 6 to 8, 1950, under the auspices of the Washington Square College of Arts and Sciences, the Institute of Mathematics and Mechanics of New York University and the Geophysical Research Directorate of the Air Force Cambridge Research Laboratories. *Interscience Publishers, Inc.* $6.50, 390 pp.—The 18 papers contained in this volume present current approaches in the use of new analytical tools and procedures and reflects revival of interest in electromagnetic problems. Essentially mathematical in character, these papers utilize Green's functions, integral equations, variational techniques and other methods in dealing with problems concerning wave propagation, wave guides, cavity theory, microwave generation and similar subjects. The material also appeared in three recent issues of the publication *Communications on Pure and Applied Mathematics.*

Studies in Large Plastic Flow and Fracture, by P. W. Bridgman. *McGraw-Hill Book Co.* $8.00, 362 pp.—The book is a coordinated exposition of many years of study of the effect of high hydrostatic pressure on the properties of matter and observance of many fractures under unusual conditions. Tension, compression, torsion, and shearing stress tests are reported. Materials studied include steel, aluminum, copper, brass, bronze, glass, beryllium, soapstone, marble and others. One chapter deals with plastic flow and fracture after prestraining.

Materials Technology for Electron Tubes, by Walter H. Kohl. *Reinhold Publishing Corp.* $10.00, 493 pp.—Materials dealt with are the main solids that enter into the construction of electron tubes; glass, ceramics and mica, tungsten, molybdenum, tantalum, nickel, copper, carbon, and graphite. Physical and chemical characteristics are tabulated and discussed, processes for application are considered, and modern techniques of construction are described. Special topics, as ceramic-to-metal seals, the phase rule, high vacuum technique, and thermionic emission, are discussed in later chapters.

Handbook of Dangerous Materials, by N. Irving Sax. *Reinhold Publishing Corp.* $15.00, 848 pp.—More than 5000 hazardous industrial materials, including trade-name products, are covered in this compilation. Placed under four major groups, they are: General chemicals; explosives; fungus diseases and fungicides; radiation and radiation hazards. Detailed information is presented on hazardous properties and situations, safety prevautions, symptoms, treatment, and antidotes, handling and storage methods, shipping regulations and other factors. The radiation section contains the most recent data available and a general discussion of the problem. The first section is alphabetically arranged, with a general index and a cross-reference system to the information contained in the volume.

Graphic Aids in Engineering Computation, by Randolph P. Hoelscher, Joseph Norman Arnold, and Stanley H. Pierce. *McGraw-Hill Book Co.* $4.50, 197 pp.—This text covers a wide range of graphical and mechanical methods and includes chapters on the standard slide rules, the derivation of empirical equations from laboratory or field data, the construction of nomographs by geometric methods and with determinents, construction of special slide rules, graphical differentiation, and movable-scale nomographs. Instructions are in detail and representative groups of problems are included for testing the student.

Fundamentals of Atomic Physics, by Saul Dushman. *McGraw-Hill Book Co.* $5.50, 294 pp.—The book is designed to give engineers and technical men a practical knowledge of atomic and nuclear fundamentals. Using a simple approach, the topics covered include the kinetic theory of gases, the charge and mass of the electron, electronics, photoelectric effects, X-rays, matter waves, isotopes, and a condensed presentation of nuclear phenomena. The last chapter gives characteristics of the several types of generators for the acceleration of high-energy particles, the cyclotron, betatron, and others.

Energy Sources—The Wealth of the World, by Eugene Ayres and Charles A. Scarlott. *McGraw-Hill Book Co.* $5.00, 344 pp.—This analysis provides a detailed review of the size of energy sources, technology of production, efficiency of conversion, and the progress being made in conversion. Oil, coal, gas, hydroelectric power, solar and nuclear energy, wind, tidal power, and other minor sources are assessed and treated according to their relative importance. The final chapter contains an energy balance sheet for the U. S.

Elements of Physical Metallurgy, by Albert G. Guy. *Addison-Wesley Press, Inc.* $6.50, 293 pp.—This is a textbook for courses in fundamentals of physical metallurgy, aimed at engineering and science students as well as metallurgy majors. An introductory section is followed by four chapters on the structure of metals and alloys. The chapter on equilibrium diagrams is the most extensive. The concept of the relationship of metallic structure and properties, with the emphasis on properties, is developed in succeeding chapters. The last four chapters deal with diffusion in metals, grain growth, age hardening, and the heat treatment of steel.

ORDER YOUR BOOKS THROUGH AIME—Address Irene K. Sharp, Book Department. Ten per cent discount given whenever possible. Order Government publications direct from the agency concerned.

PROFESSIONAL SERVICES

Limited to AIME members, or to companies that have at least one AIME member on their staffs. Rates $40 per year per inch.

S.T & CO. INC.
ENGINEERS
CONSULTANTS
METALLURGISTS
Small Jobs Welcomed
SAM TOUR & CO., INC.
Laboratories and offices
44 Trinity Place, New York 6, N. Y.
Testing—Certifying
American Standards
Testing Bureau, Inc.

LEWIS B. LINDEMUTH
Consulting Engineer
140 CEDAR STREET NEW YORK 6, N. Y.
STEEL PRODUCTION
DESIGN · OPERATION · CONSTRUCTION · METALLURGY

R. S. DEAN LABORATORIES, INC.
Consulting Research Development
Chemistry Electrochemistry & Metallurgy Laboratory Research on a Contract Basis
5810—47TH AVENUE AP 2821
RIVERDALE, MD

MAX STERN
Consulting Engineer
150 Broadway New York 7, N. Y.

T. STARLING WINTERS
Consulting Engineer
100 East Palisade Ave. Englewood, N. J.

RARE EARTH" materials, which have commanded great and growing interest even as imported from foreign sources, can now be produced in abundance within the United States.

The Molybdenum Corporation is able to report that highly modern facilities are being installed and rapid growth provided for. Technical research, looking toward new and better employment of these materials, has been extensive and will continue. Consultation with present or prospective users is invited.

As a supplier of Molybdenum, Tungsten, Boron, and other alloying materials, the Molybdenum Corporation welcomes correspondence on any application or requirement.

AMERICAN Production, American Distribution, American Control, Completely Integrated

Offices: Pittsburgh, New York, Chicago, Cleveland, Detroit, Los Angeles, San Francisco

Sales Representatives: American Steel and Supply Co., Chicago; Edgar L. Fink, Detroit; Brumley-Donaldson Co., Los Angeles, San Francisco

Subsidiaries: Cleveland-Tungsten, Inc., Cleveland, O.; General Tungsten Manufacturing Co., Inc., Union City, N.J.

Works: Washington, Pa.; York, Pa.

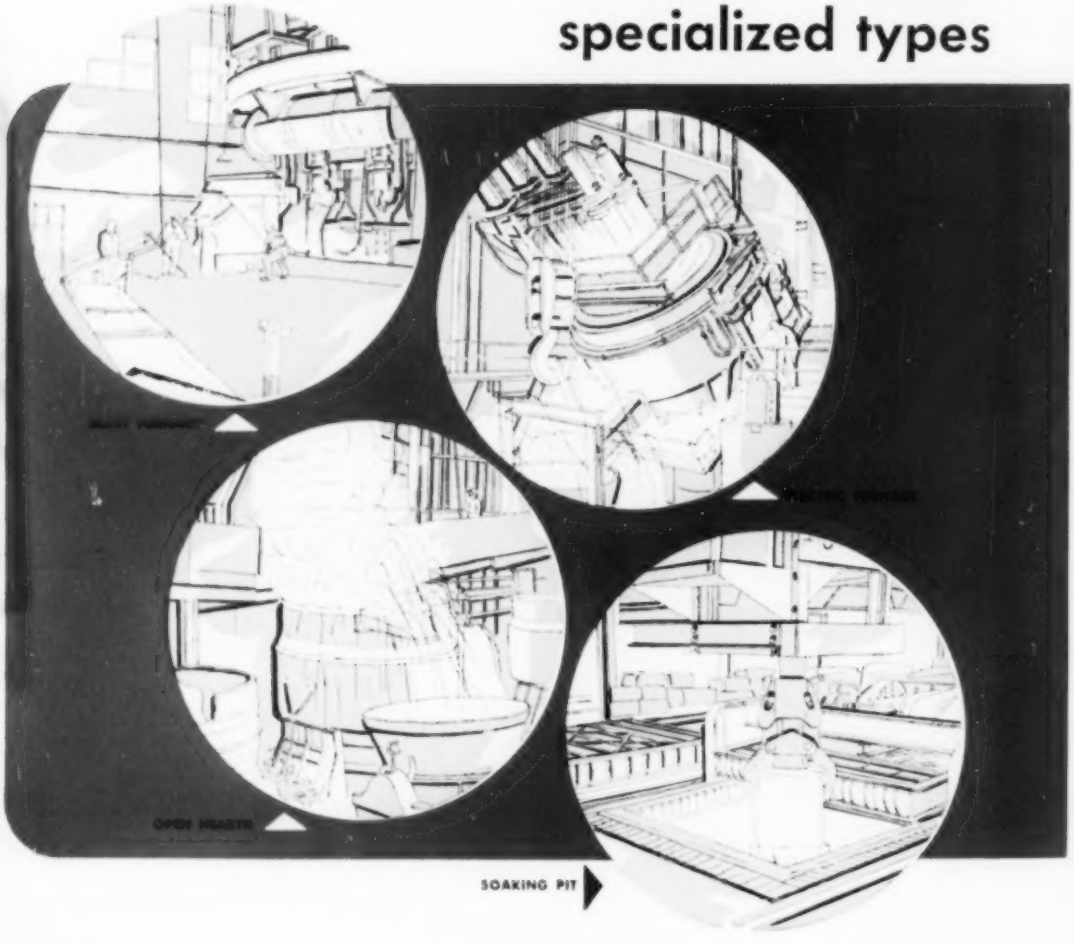
MOLYBDENUM CORPORATION OF AMERICA
Grant Building Pittsburgh, Pa.

MCA

Harbison-Steel Mill

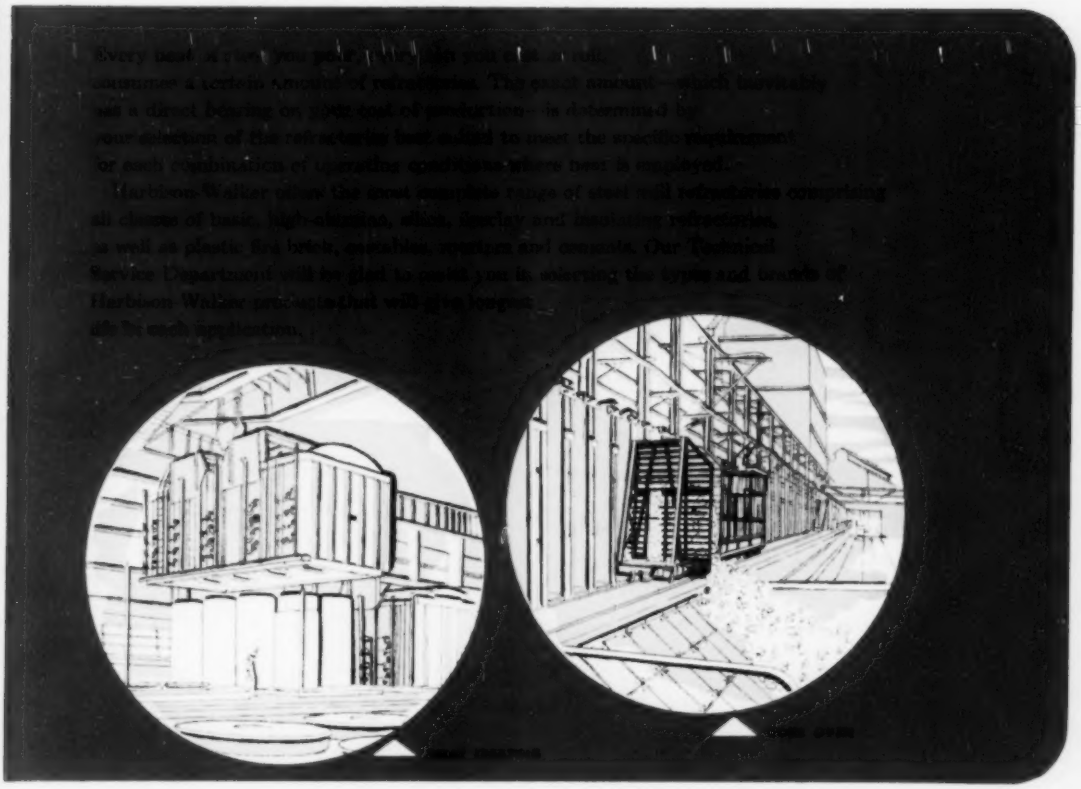
THE WORLD'S *Most Complete* REFRACTORIES SERVICE

specialized types



Walker Refractories

for every requirement

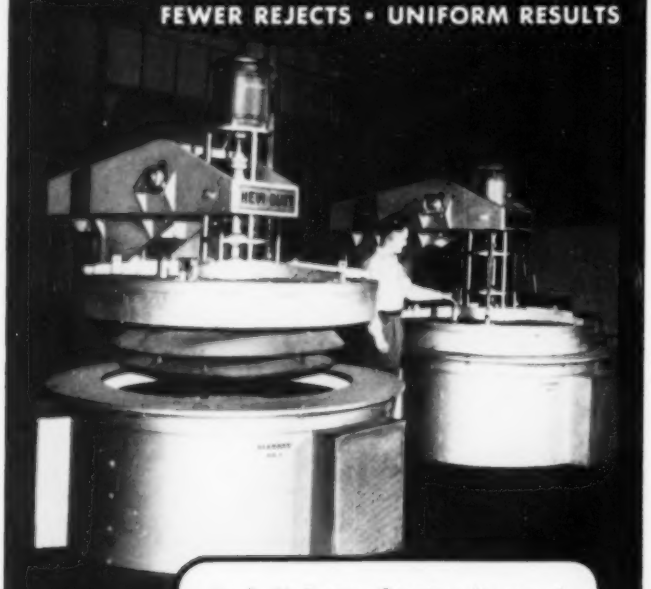


HARBISON-WALKER REFRACTORIES COMPANY
AND SUBSIDIARIES

World's Largest Producer of Refractories

General Offices: Pittsburgh 22, Pa.

IT'S THE *Reliability* OF
HEVI DUTY FURNACES
that assures
MORE PRODUCTION • LESS "DOWN-TIME" •
FEWER REJECTS • UNIFORM RESULTS



Mr. E. W. Krueger, Operations Manager of Cleveland Pneumatic Tool Co., says, "The uniformity of temperature in our Hevi Duty Pit Type Furnaces allows us to heat treat large aircraft forgings at heats and speeds adequate to meet the most exacting requirements."

These special pit type furnaces with a work space of 48" x 156" are typical of furnaces designed and built by Hevi Duty Electric Company to solve unusual heat treating problems.

The Hevi Duty return bend type heating elements are zoned to provide uniform temperatures in the entire depth of the work chamber.

For more information on how Hevi Duty Pit Type Furnaces can help you . . .

Write for Bulletin HD-1245

HEVI DUTY ELECTRIC COMPANY
HEAT TREATING FURNACES **HEVI DUTY** ELECTRIC EXCLUSIVELY
DRY TYPE TRANSFORMERS — CONSTANT CURRENT REGULATORS
MILWAUKEE 1, WISCONSIN

Industrial Notes . .

• Substantial savings in copper are being made possible by a multi-million dollar expansion program started by the Superior Steel Corp., Carnegie, Pa., using copper alloy-clad steel rather than solid gilding metal in the production of bullet jackets. The project is a joint effort by U. S. Army Ordnance and Superior Steel, and will result in the production of an additional 4000 tons per month of clad metal.

• *In addition to increasing copper production of the Capitol Foundry Co., of Phoenix, Ariz., the recent purchasers of all the capital stock of the firm, National Malleable & Steel Castings Co., intend to install electric melting furnaces and other equipment for production of cast steel grindings. The $1½ million expansion program is scheduled to begin immediately.*

• Research by Ernst Pohl, German metallurgist, may make it possible for low grade Australian coal deposits to be used for steel and pig iron production. Coal deposits of any size in Australia are of inferior grade. Similar methods for their use have been developed in Germany.

• **General Electric Co., is building a cold strip steel mill drive designed to operate a five-stand tandem mill at a top speed of 79½ mph for the Fairless works of the U. S. Steel Co. at Morrisville, Pa. The Fairless works will be the largest integrated steelmaking installation to be built in less than two years time. It has a planned capacity of 1,800,000 ingot tons of steel per year. The plant will also be equipped with a 1000 fpm annealing line and one of the largest annealing furnaces ever built. Use of amplidyne regulators for automatic tension control, loop position and overspeeding will permit the 300 ft long line to be operated by only a few men.**

• Four additional open hearth furnaces and a blast furnace will be placed in operation by summer by the Steel Co. of Canada, Ltd., in connection with its $50 million expansion program. The new units will add 1400 ingots per day to production.

• Beginning of operation of the first of two new smelting lines at the Aluminum Co. of America's Point Comfort plant near Port Lavaca, Texas, brought the plant's annual capacity to 135 million tons. The U. S. Government gets first call on the output of the two lines for the next five years. The second

• • • •

line will be finished soon. Smelting facilities are being operated through use of natural gas. Gas consumption is expected to rise from the present 30 million cu ft per day to about 50 million when full production is reached. Power plant capacity is expected to rise from 120,000 kw to about 200,000 kw. Seventy-four new Nordberg radial gas engines are being installed to supply electricity for the new potlines, in addition to the 120 in the original plant. The new units have 9 pct greater output per engine. Two new aluminum smelting plants, at Wenatchee, Wash., and Rockdale, Texas, are also under construction by Alcoa.

• **Production of a precision-type grinding wheel for the automotive and machine tool industries will be carried on in a new plant at Lackawanna to be built by Electro Refractories & Abrasives Corp. Expenditures for the plant will lift to almost $2 million the amount spent for expansion since 1947. The new product will be a vitrified clay bonded wheel.**

• Work on a new $17 million aluminum forging plant at Newark, Ohio, is scheduled to begin in the spring. The plant will be built by the U. S. Air Force and operated by Kaiser Aluminum & Chemical Corp. Two large forging presses for mass production of aircraft parts are included in the plans. One hydraulic press, with a 35,000 lb rating will be nine stories high, and will be the largest in operation in the nation. The second will have a 25,000 lb rating.

• **Kropp Forge Co., of Chicago, has succeeded in developing techniques for the production of titanium forgings in shapes and designs required by industry and defense. Bar forgings are being produced in quantity with excellent surface finishes.**

• The Erie Mining Co. is considering a development in Minnesota for production up to 10,500,000 tons annually of iron ore pellets from taconite. An application for a certificate of necessity on a basis of the estimated maximum has been filed with the Defense Production Administration. The cost has been set at about $300 million. The program calls for construction of a plant on the Mesabi Range northeast of Aurora, Minn. The initial unit is expected to have a capacity of at least 5 million tons and would take four or five years to build.

Versatility...without Costliness for

Photomicrography
Photomacrography

A highly versatile, yet inexpensive combination. Indispensable for routine photomicrography or photomacrography, with Micro-Summar lenses. For plates and cut films 3¼ x 4¼ inches, black and white or color. Accessories available for varied requirements.

Leitz MA IVb

Laboratory Camera

- Direct vision reflex housing for grain counting
- Vertical camera with bellows of 50 cm.
- Simplified time and instantaneous shutter
- Rack and pinion for lens panel
- Light-tight connecting sleeve for microscope

with

BMe

Metallurgical Microscope

- Built-in illumination
- Large, modern stand
- Rack and pinion coarse focusing
- Micrometer fine adjustment on double ball bearings
- Interchangeable large, square mechanical stage adjustable *vertically* by rack and pinion
- Dovetail slider for interchange of tubes
- Large vertical illuminator with compensating prism and plane glass

Write to Dept. Micro 1064 JM

E. LEITZ, Inc., 304 Hudson Street, New York 13, N. Y.

LEITZ MICROSCOPES • SCIENTIFIC INSTRUMENTS
BINOCULARS • LEICA CAMERAS AND ACCESSORIES

THE DRIFT OF THINGS

by Edward H. Robie

IN many ways, the Annual Meeting of the Institute in February was the most successful yet held. Attendance surpassed even that of the 75th Anniversary Meeting in 1947 with its international flavor. The number of technical sessions and the number and quality of papers presented almost certainly set a new record. The banquet was the best attended of any yet held even though the price reached a new high. Despite the demand for almost 1700 tickets to the banquet, some felt that the price—$13.50—was higher than they could afford. There are two points of view. One is that this is the big social event of the year for members and that it is worth from three to five dollars more to have it at the Waldorf and to have a luxury menu, as we did this year, with turtle soup, a fish course, guinea hen for the entree, and wild rice (which we understand is $3.50 per lb) for a vegetable. The other point of view is that a seven or eight dollar banquet of more simple food at the Commodore Hotel would more than make up in appeal, especially to the younger and less well-heeled members, what it would lack in glamour.

Men's Registration at Annual Meeting

N. Y.	641	England	10
Pa.	429	Idaho	9
N. J.	160	Kans.	9
Ohio	132	Germany	8
D. C.	113	Nev.	8
Ill.	111	N. Mex.	8
Mass.	98	Ariz.	6
Canada	93	France	6
Conn.	93	Mexico	6
Mo.	84	Belgium	5
Texas	56	Vt.	4
Mich.	56	N. H.	3
Md.	34	Oreg.	3
Calif.	33	S. D.	3
Del.	33	Ark.	2
Minn.	31	Neb.	2
Colo.	30	Sweden	2
Utah	25	Wyo.	2
W. Va.	25	Alaska	1
Ala.	24	Argentina	1
Okla.	23	Chile	1
Tenn.	21	Cuba	1
Wis.	21	Columbia	1
Ind.	18	Ga.	1
Fla.	17	Liechtenstein	1
N. C.	17	Me.	1
Ky.	11	Miss.	1
Mont.	11	Nigeria	1
Va.	11	N. D.	1
Wash.	11	S. C.	1
La.	10	Venezuela	1

Total men's registration—2570

Though meeting rooms were not entirely adequate for all of the technical sessions this year, the idea of transferring the meeting to Atlantic City, with more commodious quarters, got no support whatever. The feeling of western members seems to be that if we come East then let's go to New York and not to a summer resort in the winter time.

Those who came from particular states and countries may be interested in knowing how well their home land was represented at the meeting. The data, taken from the list of men actually registered at the meeting, are shown in the accompanying table. Without making too accurate a survey it would appear that of AIME members living within a 50-mile radius about 50 pct came to the meeting; 50 to 500 miles, about 35 pct; 500 to 1000 miles, 18 pct; and 1000 to 3000 miles, 4 pct.

Every state was represented except Iowa and Rhode Island, and 14 foreign countries were named on the registration cards.

For those who couldn't make it, remember Los Angeles, Feb. 16 to 19, 1953.

Fireside Incident

The mistress of the house, who was napping in the living room the other evening, suddenly woke up enough to inquire, "What's that noise?" "I am merely," we told her, "tearing out some of the advertising pages in the last issue of *Life* in order to get at the reading matter and pictures." "That's silly," she said, "and anyway, you shouldn't be one to object to advertising, for that pays part of your salary, and you are always saying that that's what you need more of." "But our kind of advertising is different. For one thing, it's not all mixed up with the leading articles to distract the reader's attention. And for another thing, it contains a lot of useful information and news about the latest developments in machinery which, if we were operating men, it would be in our interest to read."

"Now take these 42 pages we have just torn out. Fifteen of them, or more than one third, are advertising liquor."

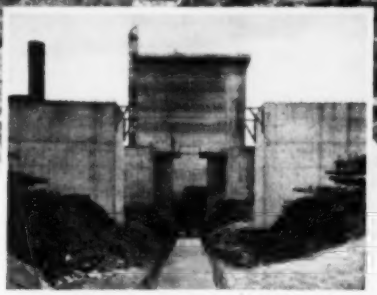
"Since when have you ceased to have any consuming interest in liquor," we were queried.

"Since our cupboard became well stocked," we replied. "And we don't believe that these brands are necessarily noted for their quality. For instance, six pages are devoted to advertising mixtures of whiskey from 60 to 70 pct alcohol, though you would never guess it from the ad. The word 'alcohol' is never mentioned once. Then there are four pages of cigarette advertising, and it must be ten years since we smoked a cigarette. And if we did take up the habit we doubt if the advertisements would give us much of a clue as to which one we like the best. We suspect that not only is cigarette smoking a habit but that the brand one smokes is equally a habit."

"I think I'll go back to sleep. That is, if you are through tearing paper."

So we stopped, and while we were thinking about the matter, browsed through the advertising pages of ME, JM, and JPT, as we call them for short. We didn't find them in the middle of an article, and we found them interesting and instructive. The next time we meet an operating engineer, we believe we can talk to him a little more intelligently.

Site of Basic Refractories' plant expansion at Maple Grove, Ohio. Two new rotary kilns and supplementary equipment are being erected. Photograph taken Jan. 25, 1952.



Close-up of twelve massive concrete piers on which the two 390-foot-long rotary kilns will rest.

As steel grows...

To improve on an old saying, "as steel grows, so grows the nation". And as steel grows, so must grow the basic refractories industry.

At Maple Grove, Ohio, Basic Refractories is expanding its capacity to produce dead-burned dolomite. Two new rotary kilns, larger than those you see in operation above, will soon double our output of Magnefer and Syndolag.

Steel kiln shells, trunnions and tires, delivered at the site early last winter, are now (mid-March) being positioned.

Raw dolomite storage silo, 122 feet high, tallest of its kind, erected in an 8-day period last December.

Basic Refractories Incorporated

845 HANNA BUILDING, CLEVELAND 15, OHIO

Exclusive Agents in Canada:
REFRACTORIES ENGINEERING AND SUPPLIES, LTD., Hamilton and Montreal

NICKEL ALLOY IRONS
develop improved properties
plus all the basic advantages of plain cast iron

PLAIN GRAY IRON is, structurally, a steel matrix containing graphite flakes. Engineering, physical, processing and service properties are wholly dependent upon the character and disposition of these flakes, and upon the nature of the matrix.

The matrix of nickel alloyed irons closely resembles the pearlitic matrix found in high carbon steels, whereas the matrix of ordinary plain iron resembles that found in low carbon steels. Compositions of nickel alloy irons can be adjusted to reduce "chill" in thin sections without risk of forming "spongy" regions in heavy sections. This promotes uniform strength, improved machinability, pressure tightness and wear resistance.

Hardness in nickel cast irons results from improvement of the matrix. Chilled areas and hard carbides, which impair machinability, are obviated. Nickel improves response to heat treating. In fact, use of nickel alone or with other alloying elements plays an important part in meeting a variety of requirements.

Accordingly . . . nickel alloyed irons permit production of castings with high levels of the following properties:

Strength

Tensile and transverse strengths of castings are greatly increased by the addition of nickel to cast irons of properly adjusted base mixture. The ratio of compressive strength to tensile strength is retained. Greater uniformity of strength in thick and thin sections is achieved.

The International Nickel Company, Inc.
Dept. JM, 67 Wall St., New York 5, N. Y.

Please send me booklet entitled, "Guide to the Selection of Engineering Cast Irons."

Name _____ Title _____

Company _____

Address _____

City _____ State _____

INCO

Elasticity

The elastic modulus increases with strength. In this respect nickel-containing irons of the high strength type possess good stiffness and do not deform permanently under loads that would be damaging to irons of lower elastic modulus.

Damping Capacity

The damping capacity inherent in gray cast iron is not impaired by the presence of nickel.

Wear Resistance

The uniformly pearlitic matrix of nickel cast irons appreciably improves wear resistance. The uniformly fine graphite flake distribution, achieved in suitably processed irons *without formation of a poor wearing dendritic condition*, affords optimum resistance to wear and galling.

Pressure Tightness

Characterized by dense grain structure and fine dispersion of graphite throughout, nickel alloy irons are close-grained and offer an extraordinary degree of pressure tightness under high hydrostatic pressures, without sacrificing machinability.

Applications

Heavy machinery frames and *beds* are typical of cast parts that benefit from the rigidity and good damping capacity of nickel cast irons. *Cylinder* and *pump liners, gears, dies, machine tool ways, saddles* and *tables* exemplify parts produced in nickel irons to assure greatly increased strength and wear resistance. And nickel alloyed iron is used for *heavy duty brake drums* to resist heat checking, thermal shock, wear and galling. The nickel cast irons are readily heat treated, and respond particularly well to flame and induction hardening.

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N. Y.

Between 10 and 20 pct more sound steel per ingot has been obtained through a new method for pouring ingots of high speed steel. The process was developed by William Jessop & Sons, Sheffield, England, in association with the British Iron & Steel Research Assn. A tile of heat resisting material is inserted into the feeder head, from which a cooling ingot draws molten steel to avoid piping or cavities. The technique may be applicable to pouring larger ingots than those used for special steels.

Mufulira Copper Mines, Ltd., Rhodesia, has formed a subsidiary, Chibuluma Mines, Ltd. largely financed by ECA funds, the subsidiary will work the Chibuluma copper-cobalt orebody, expected to produce 16,000 long tons of copper and 500,000 lb of cobalt annually by 1956. The capacity of the present company's electrolytic refinery will be increased to 72,000 tons annually by 1954. A milling capacity of 340,000 tons is expected by 1956. If the cobalt demand continues, Mufulira may form Baluba Mines, Ltd., with an annual production potential of 24,000 tons of copper and 1,100,000 lb of cobalt.

The Minerals and Metals Advisory Board of the National Research Council is recommending the further investigation and use of new machining methods, electrolytic, electro-sparking, electro-arcing, and ultrasonic processes to conserve diamond bort.

Japan's International Trade and Industry Ministry has partially lifted the export ban of ferromanganese in view of prospects for increased production.

The Bureau of Mines process for recovering manganese from open hearth slags in a blast furnace may give way to pyrometallurgical recovery methods now being investigated by the Bureau. Capitalization costs on the installation of the blast furnace method will depend on whether coke or anthracite coal can be used as fuel. A coke plant would add heavily to initial costs.

Boron containing alloy steels other than stainless steels produced during January, amounted to 2½ times as much as the average 1951 monthly production. It accounted for 9 pct of the tonnage of alloy steels other than stainless during the month.

Chile more than tripled its best previous rate of steel output in 1951, in the first year of operation of its new integrated steel plant. The country produced nearly 200,000 tons in 1951.

A saving of up to 30 pct of the electrical energy used to produce aluminum in Canada and the United States is expected through the use of a new type of long-wave electricity called "square wave." The British Columbia Aluminum Co. produced the first test bar of pure aluminum in November 1951, at its pilot plant. It is now planning expansion. A magnaquanta converter is used to produce the new type of electricity. U. S. and Canadian Government officials and Alcoa have observed the process for the past six months.

Primary aluminum production for 1951 reached 836,908 tons, a 16.5 pct increase over the 1950 output.

The Bureau of Labor statistics reports employment in the metalworking industries has steadily increased since December, in a survey made for the NPA. The rise came despite sharply reduced allotments of critical materials for civilian production during the first quarter of 1952. The survey covered 11,000 firms employing about 85 pct of the industry's labor force.

Freyn-Design

provides the steel industry with integrated... specialized... comprehensive engineering services. Consultation, design and construction. Raw materials to finished products.

1914 - - - 1952

KOPPERS

METALLURGICAL PLANT DESIGN AND CONSTRUCTION

Freyn Engineering

DEPARTMENT OF KOPPERS COMPANY, INC.

105 NORTH WABASH AVENUE · CHICAGO 2, U.S.A. · Associated with

Local Section Activities

National Open Hearth Steel Committee

BUFFALO SECTION

The Nov. 29, 1951 technical meeting of the Buffalo Section was designed to bring out the problems of the operating supervisor. Retiring chairman H. L. Allen, Jr., opened the meeting and welcomed his successor, A. K. Moore of the Steel Co. of Canada. Mr. Moore acted as technical chairman of the session. The meeting dealt with *Current Operating Problems, Practical Safety Practices,* and *Problems in Pouring Pit Practice.* Joe Walton of Bethlehem Steel Co. and Harry Northrup of Republic Steel Corp. led the discussions.

Members spent the morning visiting the Wickshire Div., Open Hearth of Colorado Fuel & Iron. A cocktail party and dinner followed the technical session. Paul Wamsley, chairman of the National Education Assn. of the American Legion, spoke to the group on the *Ramparts We Watch.*

Officers named for the coming year are: A. K. Moore, Joseph Walton, Harry Northrup, Bus Reed, John Fleming, and Harry L. Allen, Jr., all executive committee members. A fall meeting is scheduled for November.

A. K. MOORE
Steel Co. of Canada, Hamilton, Ont.
Chairman, Buffalo Section

D. R. MATHEWS
Alan Wood Steel Co., Conshohocken, Pa.
Chairman, Eastern Section

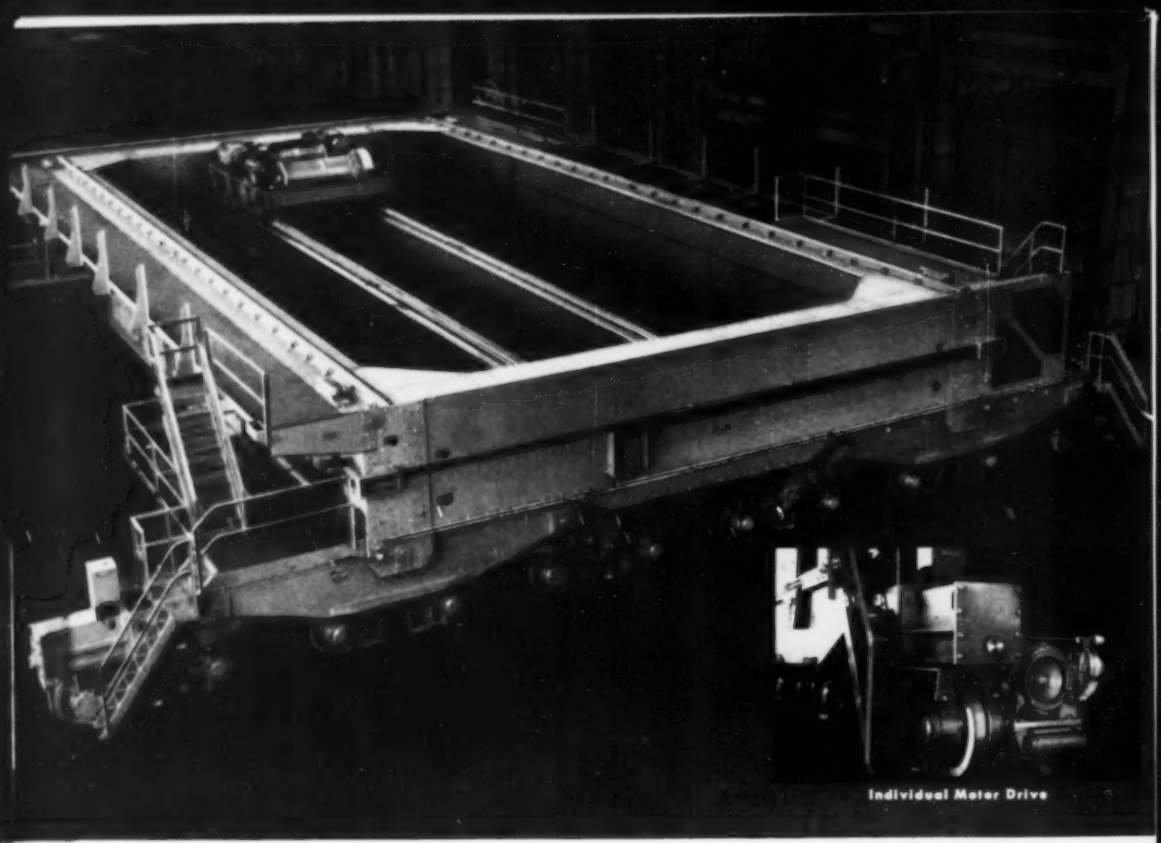
EASTERN SECTION

Increased registration marked the meeting of the Eastern Section, held Oct. 12, 1951 at the Warwick Hotel, Philadelphia. The 242 registrants attended technical sessions devoted to fuel combustion, coke gas firing, modernization and new procedures, new charging machines, jet tappers, heavy-duty torch for scrap burning, and factors contributing to loss of production. During the afternoon session safety in the open hearth, bath temperature measures, mold coating and method of application were discussed.

A reception and dinner followed the technical sessions. The diners were serenaded by Robert H. McFalls and his Cavaliers, in addition to several amateur entertainers. James E. Gheen spoke to the group in a humorous vein. Details for the evening were carried out by the Suppliers' Committee, headed by Mr. Batteiger.

Outgoing officers of the section are: D. R. Mathews, chairman, open hearth superintendent, Alan Wood Steel Co.; R. M. Baker, vice-chairman, superintendent, open hearth and bessemer, Bethlehem Steel Co.; J. R. Behrman, Alan Wood Steel Co. The section-sponsored contest for the best paper on an open hearth topic will be resumed in 1952. The next scheduled meeting is on Oct. 10, 1952.

New officers are: R. M. Baker, superintendent, open hearth and bessemer, Bethlehem Steel Co., Sparrows Point, Md., chairman; P. R. Sultzbach, superintendent, construction, the Stanley Works, Bridgeport, Conn., vice-chairman, and B. B. Hoffman, chief clerk, open hearth and bessemer, Bethlehem Steel Co., Sparrows Point, secretary-treasurer.



Individual Motor Drive

350-TON, 6-MOTOR, 76′-0″ SPAN LADLE CRANE BRIDGE

BUILT BY MORGAN Engineering

Illustrated is a 350-ton, 4-girder, 24-wheel Ladle Crane bridge with six individual motor drives.

The six motors are carried on the individual trucks, each motor being coupled to a worm reduction unit on the drive axle. With this type of drive, the usual squaring shafts are eliminated.

On account of the moving mass to be controlled, which would require the usual hydraulic brake for each drive, an air braking system is provided.

DESIGNERS • MANUFACTURERS • CONTRACTORS

BLOOMING MILLS • PLATE MILLS • STRUCTURAL MILLS

ELECTRIC TRAVELING CRANES • CHARGING MACHINES

INGOT STRIPPING MACHINES • SOAKING PIT CRANES

ELECTRIC WELDED FABRICATION • LADLE CRANES

STEAM HAMMERS • STEAM HYDRAULIC FORGING PRESSES

SPECIAL MACHINERY FOR STEEL MILLS

THE MORGAN ENGINEERING CO.

ALLIANCE, OHIO PITTSBURGH—1420 OLIVER BUILDING

PITTSBURGH SECTION

Good weather brought out 130 members and guests for the golf party held by the Pittsburgh Section June 5, one of two major events held by the group during 1951. The dinner which followed, attended by 235, saw the distribution of golf and door prizes.

On November 2, 750 members and guests attended the sixth annual Off-the-Record meeting at the William Penn Hotel. The annual affair is a joint effort by the Pittsburgh Section and the National Open Hearth Committee. C. L. Labeka of the Pittsburgh Steel Co. was program chairman of the Pittsburgh Section and S. Feigenbaum of Jones & Laughlin Steel Corp. served as program chairman for the other divisions. C. L. Labeka was assisted by D. L. McBride, W. Brandt, J. Topping, and T. J. Ondocsin in arranging technical sessions on metallurgy, operations, refractories, and acid open hearth.

A committee of H. M. Rich, chairman, R. Burke, W. T. Bolkcom, E. M. White, and W. C. Berg, Jr., handled arrangements for the suppliers' cocktail party which followed the day's activities. The Pittsburgh Section award was presented to K. Midlan, plant metallurgist, American Locomotive Corp., for a paper entitled *A Study of Some of the Physical Characteristics of Acid Open Hearth Slag*. The award will be known as the Francis L. Toy Award in the future. Toy will be presented with a plaque and certificate in recognition of his efforts for the Pittsburgh Section. Branch Rickey, Sr., general manager of the Pittsburgh Pirates, addressed the diners following the banquet.

Officers of the Pittsburgh Section are: J. F. Pollack, Jones & Laughlin Steel Corp., chairman; C. E. Williams, U. S. Steel Corp., secretary, and C. Longenecker, Blast Furnace & Steel Plant, treasurer.

T. F. POLLACK
Jones and Laughlin Steel Corp., Pittsburgh
Chairman, Pittsburgh Section

CHICAGO SECTION

J. R. BRADY
Wisconsin Steel Co., Chicago
Chairman, Chicago Section

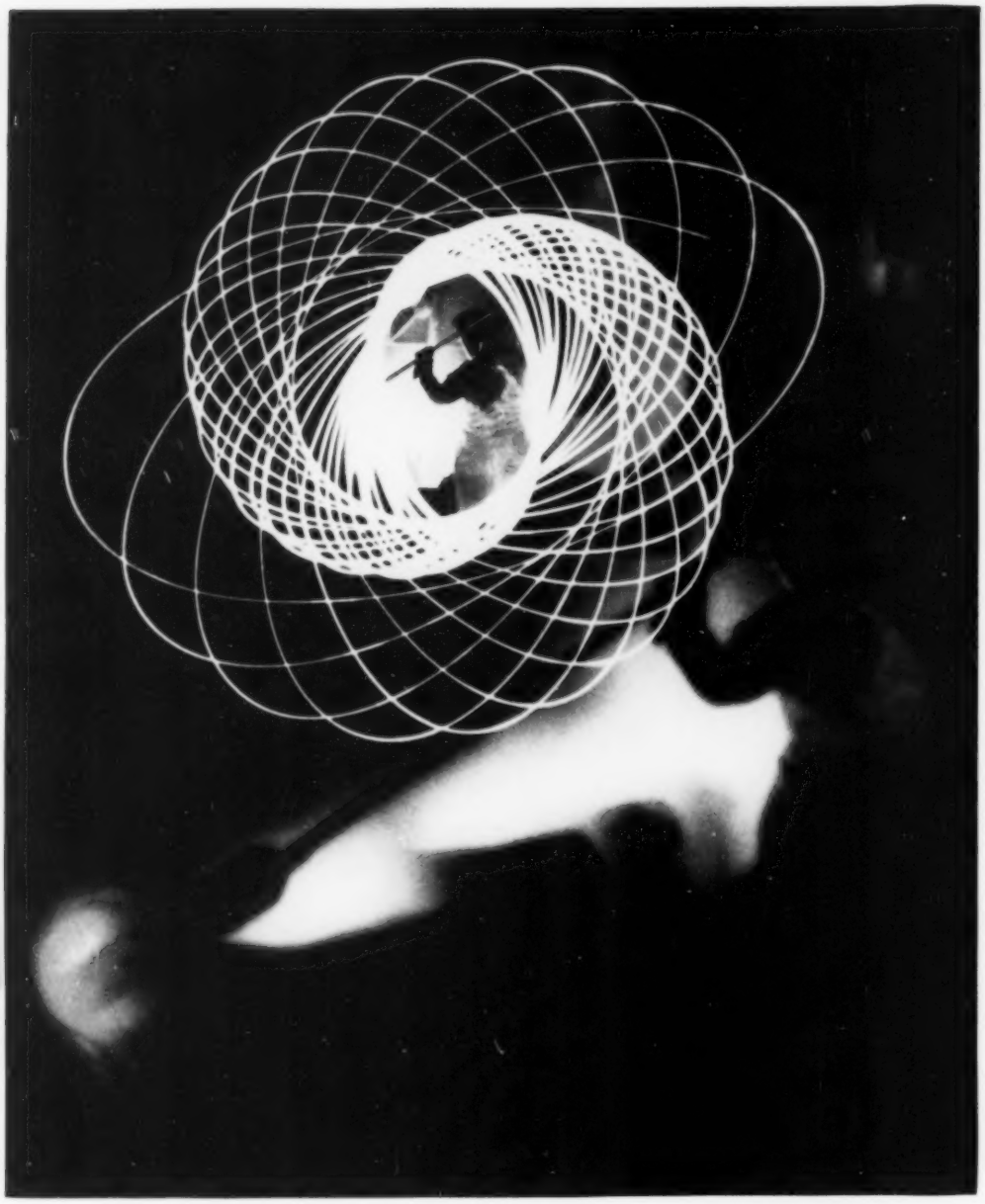
Chicago Section held its fourth annual all day meeting at the Del Prado Hotel on Mar. 14, 1951. Topics discussed were Statistical Approach to Open Hearth and Blooming Mill Operation, Progress in Open Hearth Bath Temperature Control, Factors in the Manufacture of Low Carbon Deep Drawing Rimmed and Killed Steels, Recent Developments in Open Hearth Furnace Design, Furnace Availability, and Increasing Open Hearth Production From Existing Furnaces. Sessions were followed by a cocktail party and dinner attended by 200 people. Harry Stuhldreher, assistant to the vice-president, industrial relations, U. S. Steel Co., was the speaker, and was introduced by Toastmaster F. M. Washburn, assistant general superintendent, Wisconsin Steel Co.

At the meeting on May 21, 1951, the program on Principles of Pit Practices was arranged by R. Farley, assistant chief metallurgist, Republic Steel Corp., Chicago. Over 150 operators and metallurgists attended this session.

The fourth annual golf outing was held June 13, 1951 under the chairmanship of T. J. Hess, assistant open hearth superintendent, Youngstown Sheet & Tube Co., Indiana Harbor Works. At the Fellowship dinner that followed, 200 were served.

The program for final meeting on Oct. 22, 1951 was arranged by technical chairman Oscar Pearson, superintendent steel production, Gary Works, U. S. Steel Co. Items discussed were Scrap Handling and Charging Practice, Furnace Operation (Production Problems), and Pitside Operation (Pouring Practice, Mechanical Refuse and Slag Disposal).

The officers of the section are J. R. Brady, chairman; Oscar Pearson, vice-chairman; and R. J. McCurdy, secretary-treasurer.



TITANIUM ALLOYS, produced by TAM, are used successfully as deoxidizers and stabilizers and as a source of titanium in steels and alloys. The experience gained in their development and use is available to you through our field staff and laboratory. It's yours by simply writing our New York City office.

TAM and ZIRCONITE are registered trademarks

TAM PRODUCTS
Registered U. S. Pat. Off.

TITANIUM ALLOY MFG. DIVISION
NATIONAL LEAD COMPANY

Executive and Sales Offices: 111 BROADWAY, NEW YORK CITY
General Offices, Works and Research Laboratories: NIAGARA FALLS, N. Y.

NORTHERN OHIO SECTION

The Northern Ohio Section held a golf-picnic stag party Sept. 12, 1951, at Coalburg Lake, Hubbard, Ohio. About 200 section members played golf at the Hubbard Country Club. E. E. McGinley, div. superintendent, steel production, Ohio Works, U. S. Steel, was elected chairman for the coming year by a meeting of 14 members of the executive committee at the Youngstown Club. Also elected was B. H. Ramage, open hearth practice engineer, Youngstown Sheet & Tube Co., secretary treasurer.

Tentative plans were made for the spring technical session by the executive committee. The session was held March 4 at the Hotel Pick Ohio, Youngstown. On the agenda were: *Factors Influencing Open Hearth Heat Time, Usage of Silica Brick, Labor Saving Devices in Slag Removal and Flue Cleaning, and Spectroscopic Control of Blow and Conservation of Manganese in Bessemer Process.*

T. B. Carbender, superintendent, O. H. Brier Hill Works, Youngstown Sheet & Tube, and E. R. Holstein, superintendent, bessemer, Ohio Works, U. S. Steel, were co-chairmen of the technical sessions.

The session was followed by a cocktail hour and dinner. J. W. Owings, assistant general manager of sales, Youngstown Sheet & Tube, spoke to the diners on *Pig Iron and Politics*. Attendance at the session was 281.

E. E. McGINLEY
U. S. Steel Co., Youngstown
Chairman, Northern Ohio Section

GEORGE B. McMEANS
Kaiser Steel Corp., Fontana, Calif.
Chairman, Western Section

BARNEY DAGAN
Kaiser Steel Corp., Fontana, Calif.
Presiding Chairman, Western Section

WESTERN SECTION

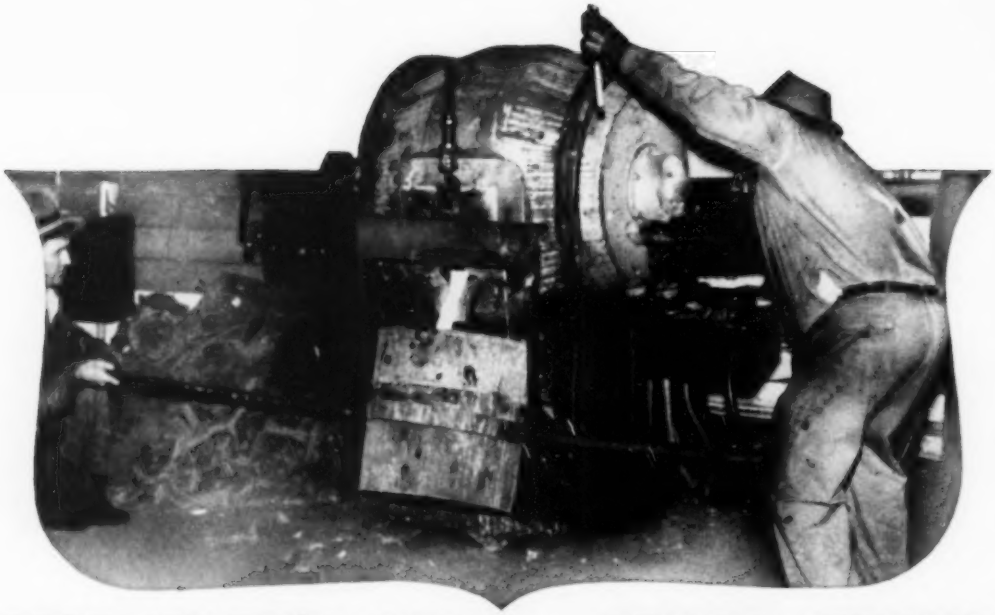
Meetings of the Western Section have been devoted to subjects concerning both open hearth and electric furnace steel operations. Programs were arranged in order to appeal to all of the members. All meetings are held at the Rodger Young Auditorium in Los Angeles, and the attendance ranged from 70 to 85 members at each session.

On Sept. 19, 1951, E. F. Donatic, division superintendent, services, Kaiser Steel Corp., spoke on *Steel Mill Maintenance*. On Oct. 10 and 11, 1951, the Section participated with the Southwestern Section in a two-day meeting at Pueblo and Colorado Springs. John S. Marsh, research engineer, Bethlehem Steel Co., Bethlehem, presented a talk on the *Making of Basic Electric Ingots* at the Nov. 4, 1951 meeting. Those attending the Jan. 16, 1952 session heard a paper on *Proper Refractories Cut Cost of Steel* by C. E. Grigsby, service research engineer, General Refractories Co., Philadelphia.

The concluding meeting was held Mar. 26, 1952, at which time C. D. King, assistant vice-president and chairman, Engineering Committees, U. S. Steel Co., Pittsburgh, spoke on *Some Observations on Past, Present and Future Ingot Production.*

An award made available by Don Watkins for the best paper prepared during the year was presented at this meeting.

Officers for this year are: George B. McMeans, Kaiser Steel Corp., permanent chairman; Barney Dagan, Kaiser Steel Corp., presiding chairman; John Fahey, American Manganese Steel Div., vice chairman; and S. L. Jackson, Electro Metallurgical Co., secretary-treasurer. Board members serving are: J. T. Evans, Jr., National Supply Co.; B. G. Emmett, Los Angeles Steel Casting Co.; Ralph Price, Bethlehem Pacific Coast Steel Corp.; Glenn E. Middleton, National Supply Co.; John T. Oursler, Columbia-Geneva Steel Div., U. S. Steel Co.; and H. R. Brookman, U. S. Lime Products Corp.



THE HEAT'S ON for MORE HEATS

FROM YOUR DETROIT ELECTRIC FURNACES

Here's the "*inside story*" on how to get them!

Now, with defense requirements demanding more and more metal production, you can't afford to be delayed by frequent furnace shut-downs. Detroit Electric Furnaces, lined with Taylor Sillimanite (TASIL) brick and shapes, are setting new records for long, efficient operation and lower refractory costs per ton of metal melted. Specify TASIL linings and keep that metal pouring!

FOR EXAMPLE:

At a foundry in Indiana, a 350 lb. "LFC," lined and maintained with TASIL brick and TASIL cements, is still going strong after producing more than 9000 heats of 85-5-5-5 brass over a 28½ month period! That's ample evidence why an increasing number of foundries have standardized on TASIL linings.

TASIL bricks and shapes possess many desirable properties that increase furnace lining life. They have high hot load strength; high softening point (3335° F.); high volume stability throughout the temperature range; excellent resistance to spalling and slagging. Lining life may be further prolonged by maintaining with one of several types of TASIL Patches and Cements especially "engineered" for this job. Contact the Taylor representative in your area or write direct for complete information on TASIL linings for Detroit Electric Furnaces. There is no obligation.

TASIL Detroit Electric lining being pre-assembled at the Chas. Taylor plant. All linings are fitted to gauge (supplied by the Detroit Electric Furnace division, Kuhlman Electric Company) and are match marked for assembly, before shipment.

Exclusive Agents in Canada:
REFRACTORIES ENGINEERING AND SUPPLIES, LTD.
Hamilton and Montreal

The CHAS. TAYLOR SONS Co.
A SUBSIDIARY OF NATIONAL LEAD COMPANY
REFRACTORIES SINCE 1864 • CINCINNATI • OHIO • U.S.A.

SOUTHWESTERN SECTION

Registration for the spring, 1951, meeting of the Southwestern Section, held at St. Louis Feb. 21, 1951, concurrently with the AIME Annual Meeting, totaled 170. Three main topics on the meeting agenda were: *Problems Concerning Pouring of Rimmed Steel*, led by C. C. Brown of Inland Steel Co., and Marcel Terris, Granite City Steel Co.; *Use of Special Refractories to Increase Furnace Life in Cold Metal Shops*, led by Paul Aiken of the Laclede Steel Co.; and *Pit Refractories*, under the chairmenship of Jesse L. Jennings, General Steel Castings Co., and Russell Solomon, Granite City Steel Co. The technical session was followed by a cocktail hour and Fellowship dinner.

Delegates to the fall meeting began to arrive at Pueblo on the morning of October 10, for the two-day meeting. Colorado Fuel & Iron Corp. met the incoming members at the station and provided transportation. No general sessions were scheduled for the first day. The Lavino Co. played host to the delegates at a dinner and cocktail party in the evening.

William H. Carpenter, process control metallurgist of CF&I, presided as chairman of the technical session on October 11. The delegates heard Don Baughman, Sheffield Steel Corp., Kansas City; Walter Serge, Jones & Laughlin Steel Co., Pittsburgh; Rudolph Smith, Colorado Fuel & Iron Corp., Pueblo; Martin Schuster, Granite City Steel Co., Granite City, Ill.; Gordon Yocum, Wheeling Steel Corp., Steubenville, Ohio; Gordon McMillan, General Steel Castings, Granite City; and Frank Hahn, Scullin Steel Co., St. Louis. Following the technical session, the delegates were entertained by CF&I, at a dinner.

Headquarters for the spring, 1952, meeting was the Lennox Hotel, St. Louis. The meeting was held February 8, with the following papers presented at the sessions: *Bath Pyrometry in Basic Steel Foundries and Ingot Shops*, F. Von Gruenigen, American Steel Foundries, Granite City; *Slag Control*, W. H. Carpenter, Colorado Fuel & Iron Corp.; W. H. Steinheider, Sheffield Steel Corp., Kansas City; *Control of Low Carbon Rimmed and Killed Steel for Deep Drawing Quality*, Paul Stuko, Youngstown Sheet & Tube Co., Youngstown; *Oxygen in the Open Hearth*, Charles Drabers, Wheeling Steel Corp.; *Planning and Scheduling Furnace Repairs in a Cold Metal Shop*, J. E. Wilbanks, Atlantic Steel Co., Atlanta; *Rimmed Steels, Capping Practice, Bleeding, Etc.*, Marcell Tarris, Granite City Steel Co., Granite City, Ill.; and W. H. Carpenter; and *Refractories in Cold Metal Operations*, A. H. Sommer, Keystone Steel & Wire, Peoria, Ill.

William H. Carpenter and Huey Clark, melted metals superintendent, American Steel Foundries, East St. Louis, Ill., will serve as chairman and vice-chairman respectively, for the coming year. Ed Christopher was appointed to succeed Donald MacArthur, who resigned as secretary-treasurer. Andrew Harrison, Mexico Refractories, Kansas City, will assist Mr. Christopher.

Members of the nominating committee are: W. A. Peters, Laclede Steel Co.; Dan Murphy, Scullin Steel Co.; and Russell Solomon, Granite City Steel Co.

The Globe Trotters will be the guests of Al Sommer at the fall meeting in October 1952, scheduled for Peoria.

CLARENCE L. KING
Sheffield Steel Corp., Kansas City, Mo.
Chairman, Southwestern Section

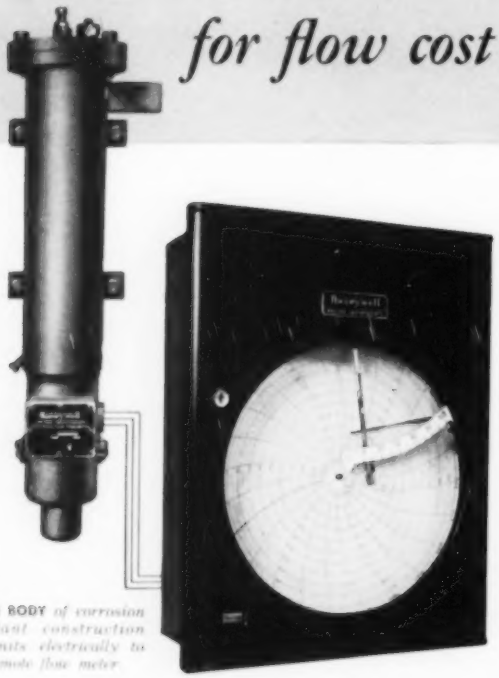
VERNON JONES
Armco Steel Corp., Middletown, Ohio
Chairman, Southern Ohio Section

SOUTHERN OHIO SECTION

The 15th Annual Meeting of the Southern Ohio Section was held at the Deshler-Wallick Hotel, Columbus, on October 26 to 27, with 211 attending. The following papers were presented during the meeting: *Safety in the Open Hearth*, Robert S. B. Holmes, director of training and safety, National Tube Co., Pittsburgh; *Survey of Flush Practices*, Richard W. Lewry, open hearth superintendent, Detroit Steel Corp., Portsmouth, Ohio; *Economics of Scrap Preparation*, Harlan W. Jarvis, purchasing agent, Armco Steel Corp., Middletown; *Improving Furnace Availability by Scheduling Rebuilds*, L. R. Astie, assistant general foreman of labor, brick and riggers dept., Jones & Laughlin Steel Corp., Pittsburgh; *Barnyard Economics*, W. F. Johnston, supervisor of training, Armco Steel Corp.; *Effect of Hot Metal Temperature on Proportioning of Heats and Production Rate*, Stanleigh Elam, senior metallurgist, Armco Steel Corp., Ashland, Ky.; *Statistics As a Tool in Production and Quality Control in the Open Hearth*, Frank G. Norris, metallurgical engineer, Wheeling Steel Corp.; and *Some Factors Affecting Mold Life*, Arthur P. Woods, research engineer, Armco Steel Corp., Middletown.

Charles W. Cover, Zanesville plant, Armco, served as Toastmaster at the Fellowship dinner. Louis J. Albers, recently returned from a trip along the edges of the Iron Curtain, addressed the dinner on conditions in that part of the world. The 1952 meeting will be held October 3, at the Deshler-Wallick. Vernon W. Jones, chairman, G. H. Todd, vice-chairman, and H. P. Gaw, secretary-treasurer, will continue in office.

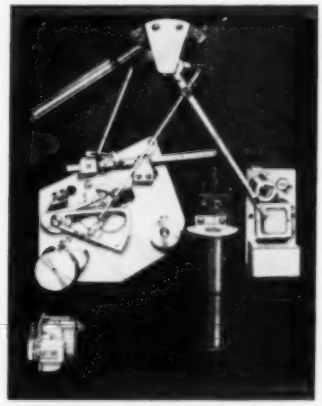
New evenly graduated flow meter *for flow cost accounting*



METER BODY *of corrosion resistant construction transmits electrically to the remote flow meter.*

FLOW METER *with evenly divided chart is uniformly accurate . . . easy to read at all rates of flow.*

ELECTRONIC INTEGRATOR *is fast, accurate . . . eliminates slow, complicated totalizing . . . simple to service.*



AN IMPORTANT development in flow instrumentation—the Brown Evenly Graduated Flow Meter—brings new accuracy and convenience to flow cost accounting of steam, oil, gas and water.

Because the instrument scale is *evenly graduated*, you can read flow at full accuracy and with equal ease at any part of the range. No more squinting or troublesome interpolation due to crowded divisions at the low end of the scale.

Electronic integration adds up total flow accurately on a six-digit direct reading counter . . . tells how much fluid has gone through the metered line. Continuous integration eliminates the labor and uncertainties of totalizing from intermittent measurements. The new integrator features simplified design with only three major parts, all readily accessible for inspection and maintenance.

The compact electric meter body is easily mounted anywhere. It is designed of corrosion resistant materials to assure constant calibration. Electric transmission permits location of the recorder hundreds of feet from the meter body without loss of response or accuracy.

Call in your local Honeywell engineering representative for a discussion of your flow applications . . . he is as near as your phone.

MINNEAPOLIS-HONEYWELL REGULATOR CO., *Industrial Division*, 4573 Wayne Ave., Philadelphia 44, Pa.

MINNEAPOLIS
Honeywell
BROWN INSTRUMENTS
First in Controls

● *Important Reference Data*

Write for Bulletin No. 293-2, "Brown Evenly Graduated Flow Meter"

A. H. SOMMER
Chairman

National Open Hearth Steel Conference

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS
NATIONAL OPEN HEARTH STEEL COMMITTEE
IRON & STEEL DIVISION

Committee on
BLAST FURNACE, COKE OVEN and RAW MATERIALS
IRON & STEEL DIVISION

Members and Friends:

The Board of Directors of the American Institute of Mining and Metallurgical Engineers, and the Executive Boards of the Blast Furnace, Coke Oven and Raw Materials Committee, and the National Open Hearth Steel Committee, extend to you a cordial invitation to attend the 34th Conference to be held in the William Penn Hotel, Pittsburgh, on Monday, Tuesday, and Wednesday, Apr. 24 to Apr. 26, 1950.

We are pleased to report, that through the combined efforts of the Blast Furnace, Coke Oven, and Raw Materials Committee, Open Hearth Committee, and Physical Chemistry of Steelmaking Committee an interesting and comprehensive program has been prepared.

On Monday and Tuesday, sessions will be held on increasing open hearth production, operating metallurgy, refractories and masonry, fuels and combustion, cold metal and basic foundry practice, training open hearth personnel, blast furnace operating, beneficiation, and coal and coke. Wednesday will be devoted to a plant trip.

The speaker for the dinner will be E. J. Kiely, Executive Vice-President, U. S. Steel Co. Gen. Gordon Somervell, Chairman of the Board, Koppers Co., will be the toastmaster.

A cordial invitation is extended to all to attend the informal reception at 5:30 on Tuesday and the Annual Fraternity Dinner which will follow at 7:30 pm.

The Conference Committees have spent much time in arranging this extensive program and we wish at this time to extend our thanks and appreciation for their wholehearted cooperation.

E. K. Miller, Chairman
Blast Furnace, Coke Oven and Raw Materials Committee

A. H. Sommer, Chairman
National Open Hearth Steel Committee

Annual Blast Furnace, Coke Oven and Raw Materials Conference, March 31, April 1, 2, 1950, Pittsburgh, Pa.

Blast Furnace, Coke Oven and Raw Materials Conference

Chairman
E. K. MILLER

C. C. RUSSELL

SAMUEL NAISMITH

Blast Furnace, Coke Oven and Raw Materials Committees

E. K. Miller, Chairman

Samuel Naismith, Vice Chairman

C. C. Russell, Vice Chairman

Kurt Neustaetter, Secretary

Program Committee

H. P. Sauer, Chairman

G. R. Baer

J. J. Cavett

W. H. Holman

R. F. Liggett

W. E. Marshall

M. F. Morgan

Finance Committee

R. S. Carey, Chairman

Britt Day

J. G. Greenwood

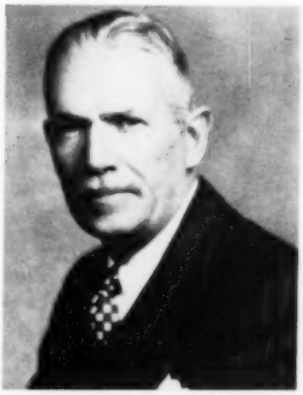
J. C. Murray

V. J. Nolan

H. A. White

KURT NEUSTAETTER

Toastmaster:
GEN. BREHON D. SOMERVELL,
Chairman of the Board,
Koppers Co., Inc.



H. M. GRIFFITH

J. J. GOLDEN

National Open Hearth Steel Committee

A. H. Sommer, Chairman
Keystone Steel & Wire Co., Peoria, Ill.

J. J. Golden, Vice-Chairman
U. S. Steel Co., Pittsburgh

H. M. Griffith, Past Chairman
Steel Co. of Canada, Ltd., Hamilton, Ont.

Ernest Kirkendall, Secretary
AIME, New York

Executive Board

L. R. Berner
Inland Steel Co., E. Chicago, Ind.

G. M. Burrier
Crucible Steel Co. of America, Midland, Pa.

C. E. Carr
Wheeling Steel Co., Wheeling, W. Va.

T. A. Cleary
Youngstown Sheet & Tube Co., Youngstown

A. F. Franz
Colorado Fuel & Iron Corp., Denver

H. G. Grim
Hoppenwell Co., Pittsburgh

C. F. Henzelman
Bethlehem Steel Co., Johnstown, Pa.

V. W. Jones
Armco Steel Corp., Middletown, Ohio

A. C. Keller
Jones & Laughlin Steel Corp., Aliquippa, Pa.

D. R. Mathews
Allen Wood Steel Co., Conshohocken, Pa.

A. W. Thornton
National Tube Co., McKeesport, Pa.

F. L. Toy
U. S. Steel Co., Pittsburgh

H. J. Walker
Republic Steel Corp., Warren, Ohio

Clyde Williams
Battelle Memorial Institute, Columbus

Speaker:

C. F. HOOD, Executive Vice-President, U. S. Steel Co.

ERNEST KIRKENDALL

Technical Program

BLAST FURNACE, COKE OVEN AND RAW MATERIALS COMMITTEE

MONDAY, MARCH 31

9:30 am to 12:15 pm—Urban Room

BLAST FURNACE OPERATING SESSION

Chairmen:

R. P. Liggett, General Superintendent Blast Furnaces, Republic Steel Corp., Cleveland.

W. R. Trognitz, Superintendent Blast Furnaces, U. S. Steel Co., Braddock, Pa.

1. **Results Following the Installation of 35 Psi Pressure Turbo Blower:**
   J. J. Shannon, Superintendent Blast Furnaces, Tennessee Coal, Iron & R. R. Co., Ensley, Ala. (Preprinted)
2. **Blast Furnace Operation with Controlled Differential Pressure:**
   L. W. Adams, Jr., Superintendent Blast Furnace Dept., Pittsburgh Coke & Chemical Co., Neville Island, Pittsburgh. (Preprinted)
3. **Experience with Conditioned Blast at Woodward Iron Co.:**
   H. A. Byrns, General Superintendent, Woodward Iron Co., Birmingham, Ala. (Preprinted)
4. **Multiple Correlation of Blast Furnace Variables:**
   R. V. Flint, Industrial Engineering Div., U. S. Steel Co., Pittsburgh. (Preprinted)

2:00 pm to 5:00 pm—Monongahela Room

BENEFICIATION SESSION

Chairmen:

W. E. Marshall, Research Metallurgist, Armco Steel Corp., Middletown, Ohio.

F. M. Hamilton, Ore Research Laboratory, Jones & Laughlin Steel Corp., Negaunee, Mich.

1. **The Krupp-Renn Process—A Direct Process for Silicious Iron Ores:**
   F. Johannsen, Professor, Bergakademie Clausthal, Germany. (Preprinted)
2. **Heat Hardening of Taconite Pellets:**
   G. V. Woody, Manager, Basic Industries Dept., Allis Chalmers Mfg. Co., Milwaukee.
3. **Self Fluxing Sinters:**
   John Peast, Assistant Blast Furnace Superintendent, Armco Steel Corp., Hamilton, Ohio. (Preprinted)

TUESDAY, APRIL 1

9:30 am to 12:15 pm—Urban Room

BLAST FURNACE SESSION

Chairmen:

G. R. Baer, Metallurgical Engineer, Freyn Engineering Dept., Koppers Co., Chicago.

D. P. Cromwell, Assistant Manager Blast Furnaces & Coke Ovens, Ford Motor Co., Dearborn.

1. **Operation of an Experimental Blast Furnace:**
   R. C. Buehl, Chief Ferrous Pyrometallurgy Section and M. B. Royer, Metallurgist, Ferrous Pyrometallurgy Section, U. S. Bureau of Mines, Pittsburgh. (Preprinted) Includes motion picture.
2. **The Manganese Distribution Between Slag and Metal Under Reducing Conditions:**
   J. E. Stukel, Development Engineer, Youngstown Sheet & Tube Co., Youngstown.
3. **Blast Furnace Burdening for Coke of Varying Qualities:**
   C. M. Squarcy, Assistant Superintendent No. 2 Blast Furnaces, Inland Steel Co., Indiana Harbor Works, E. Chicago. (Preprinted)
4. **The Present Situation Regarding Fireclay and High Alumina Refractories for Blast Furnace Linings:**
   J. A. Pierce, Research Engineer, and R. E. Birch, Director of Research, Harbison-Walker Refractories Co., Pittsburgh. (Preprinted)

2:00 pm to 5:00 pm—Monongahela Room

COAL AND COKE SESSION

Chairmen:

J. J. Cavett, Superintendent, By-Product Coke Plant, Jones & Laughlin Steel Corp., Aliquippa.

L. A. Kraemer, Project Engineer, Sales Dept., Engineering & Construction Div., Koppers Co., Pittsburgh.

1. **Coal and Coke Research:**
   C. L. Potter, Supervisor of Coal and Coke Research Div., Jones & Laughlin Steel Corp., Pittsburgh.
2. **Tromp Heavy Media Washing Process:**
   John Griffen, Consulting Engineer, McNally-Pittsburg Mfg. Corp., Pittsburgh. (Preprinted)
3. **The Overall Efficiency of Coal Washing:**
   J. D. Price, Superintendent Coke Plant, Colorado Fuel & Iron Corp., Pueblo. (Preprinted)
4. **Free Expansion Coke Ovens and the Use of High Volatile Coal to Produce Metallurgical Coke:**
   Daniel Petit, Consulting Engineer, Societe de Technique Industrielle, 20 bis, Rue La Boetie, Paris, France. (Preprinted)

2:00 pm to 5:00 pm—Urban Room

BLAST FURNACE GENERAL SESSION

Chairmen:

W. H. Holman, Superintendent Blast Furnaces, Wheeling Steel Corp., Mingo Junction, Ohio.

C. G. Hogberg, Assistant to Chairman, Blast Furnace Committee, U. S. Steel Corp., Pittsburgh.

1. **Greenawalt Sintering Plant:**
   J. A. Poll, Assistant Plant Manager, National Lead Co., Tahawus, N. Y. (Preprinted)
2. **A Practical Application of Ore Sizing:**
   W. R. Kerr, Blast Furnace Practice Man, Blast Furnace Dept., Kaiser Steel Corp., Fontana, Calif. (Preprinted)
3. **A Comparison of Blast Furnace Operation with and without Coke Produced from Pennsylvania Low Volatile Coals:**
   W. C. M. Bennett, Superintendent Blast Furnaces, U. S. Steel Co., Rankin, Pa. (Preprinted)
4. **Physical Conditions in the Combustion and Smelting Zones of a Blast Furnace:**
   J. F. Elliott, Inland Steel Co. (formerly U. S. Steel Co., Research Laboratory), R. A. Buchanan and J. B. Wagstaff, Research Laboratory, U. S. Steel Co., Kearny, N. J. (Preprinted) Includes motion picture.

NATIONAL OPEN HEARTH STEEL COMMITTEE

AUTHORS AND CHAIRMEN BREAKFASTS

Monday and Tuesday, March 31 and April 1

8:00 am — Fort Duquesne Room

Authors and session chairmen of the day will meet for breakfast followed by an opportunity to plan final details with regard to the schedule of papers for each session on that day.

MONDAY, MARCH 31

9:30 am to 10:15 am — Ballroom

OPEN HEARTH GENERAL SESSION

1. **Welcoming Remarks**
   By A. H. Sommer, Superintendent of Steel Mills, Keystone Steel & Wire Co., Peoria, Ill., General Chairman, National Open Hearth Committee, AIME
2. **Announcements and Reports**
3. **McKune Award Paper**

10:30 am to 12:15 pm — Ballroom

INCREASING OPEN HEARTH PRODUCTION

Chairmen:

H. L. Tear, Assistant Superintendent, Open Hearth, Jones & Laughlin Steel Corp., Pittsburgh.

E. J. Dattisman, Jr., Assistant Div. Superintendent Open Hearth, U. S. Steel Co., Munhall, Pa.

1. **Checker Maintenance to Increase Flame Intensity:**
   - A. Benefits obtained from insulating and sealing checkers
   - B. Methods of measuring air leakage
   - C. Cleaning

   L. A. Hovey, Superintendent Open Hearth No. 4, U. S. Steel Co., Munhall, Pa.
2. **Use of Oxygen for Flame Enrichment and Decarburization:**
   - A. M. Kroner, Assistant Superintendent, Inland Steel Co., E. Chicago, Ind.

   Oscar Pearson, Chief Metallurgist, U. S. Steel Co., Gary, Ind.
3. **Methods of Decreasing Charging Time:**
   - A. Scrap preparation and method of distributing light and heavy scrap
   - B. Scrap bailing
   - C. New equipment
   - D. Pan size

   Barney Dagan, Assistant General Superintendent, Kaiser Steel Corp., Fontana, Calif.

   V. W. Jones, Superintendent Steel Production, Armco Steel Corp., Middletown, Ohio

11:00 am to 2:00 pm — Fort Duquesne Room

ACID OPEN HEARTH

ROUND TABLE DISCUSSION AND LUNCHEON

Chairmen:

H. E. Klugh, Assistant Foundry Superintendent, United Engineering & Foundry Co., New Castle, Pa.

R. M. Barnhart, Open Hearth Superintendent, American Locomotive Co., Latrobe, Pa.

1. **The advantages of insulation of the bulk heads and back walls**
2. **The effect of automatic reversal and furnace pressure control on increasing efficiency**
3. **The advantages of super duty brick on the roof**
4. **Roof temperature control**
5. **Scrap**
6. **Charge—pig iron substitutes; charged manganese and silicon**
7. **Bath temperature control by the immersion thermocouple**

Chairs will be available other than those at the luncheon tables for those who do not plan to have lunch. Luncheon tickets cost $3.50.

LUNCHEON

Tuesday, April 1

12:30 to 2:00 pm — Fort Duquesne Room

Annual Luncheon and Business Meeting, Blast Furnace, Coke Oven and Raw Materials Committee

E. K. Miller, Chairman

Everyone attending the Blast Furnace, Coke Oven and Raw Materials sessions is invited to attend this luncheon and annual business meeting.
(Tickets $3.50, tips and tax included; see page 3.)

ANNUAL FELLOWSHIP DINNER

Tuesday, April 1

6:30 pm — Urban Room

Reception and Cocktail Party for dinner guests

7:00 pm — Ballroom

Annual Fellowship Dinner

Toastmaster: Gen. Brehon Somervell, Chairman of the Board, Koppers Co., Pittsburgh.

Speaker: C. F. Hood, Executive Vice-President, U. S. Steel Co., Pittsburgh.

Music: Homestead District Works Male Chorus of U. S. Steel Co.

2:00 pm to 5:00 pm — Urban Room

REFRACTORIES AND MASONRY

Chairmen:

W. J. Scharfenaker, Mason Superintendent, Steel Div., Ford Motor Co., Dearborn.

E. B. Snyder, Refractories Engineer, Wheeling Steel Corp., Steubenville, Ohio.

1. **Use of Plastic and Castable Refractories:**

A. Rammed fantails.

R. R. Fayles, Superintendent, Refractories & Fuels, Lukens Steel Co., Coatesville, Pa.

Discussion by W. E. Haberthur, Masonry Superintendent, Jones & Laughlin Steel Corp., Pittsburgh.

B. Castable in flue construction.

J. C. Witherspoon, Assistant to General Superintendent, American Steel & Wire Co., Donora, Pa.

Discussion by R. E. Wright, Mason Superintendent, U. S. Steel Co., Clairton, Pa.

2. **Industry Survey of Zebra Roof Experience:**

T. H. Harley, Ceramic Engineer, Steel Div., Ford Motor Co., Dearborn, Mich.

3. **Recent Experience with Rammed Hearths:**

H. M. Kraner, Ceramic Engr., Bethlehem Steel Corp., Bethlehem, Pa.

Discussion by W. Brandt, Superintendent No. 4 Open Hearth, U. S. Steel Co., Homestead, Pa.

4. **Planning and Scheduling Furnace Repairs to Increase Availability:**

J. L. Walton, Open Hearth Superintendent and J. O. Dague, Assistant Superintendent, Mechanical Dept., Bethlehem Steel Corp., Lackawanna, N. Y.

Discussion by Jack Reed, Mason Superintendent, U. S. Steel Co., Gary, Ind.

5. **Hot Metal Mixer Linings:**

R. E. Atkins, Assistant Superintendent, Open Hearth & Foundry, Columbia-Geneva Steel Div., U. S. Steel Co., Geneva, Utah.

Discussion by F. R. Smith, Open Hearth Superintendent, Clairton Works, U. S. Steel Co., Pittsburgh.

2:00 pm to 5:00 pm — Ballroom

OPERATING METALLURGY

Chairmen:

J. S. Marsh, Research Engineer, Bethlehem Steel Co., Bethlehem, Pa.

C. R. Taylor, Supervising Metallurgist, Armco Steel Corp., Middletown, Ohio.

1. **Conservation of Alloys:**

A. Manganese conservation through changes in deoxidation practice and timing.

B. Use of substitute materials for aluminum in all grades of steel.

C. Review of methods for adding boron.

D. Use of exothermic alloys.

D. L. McBride, National Academy of Sciences, Metallurgical Advisory Board, Washington, D. C.

C. C. Brown, Metallurgist, Inland Steel Co., E. Chicago, Ind.

E. W. Pierce, Chief Metallurgist, U. S. Steel Co., Chicago.

2. **Effect of Various Elements on Hot Workability:**

A. A review of Physical Chemistry of Steelmaking Committee Manganese Symposium.

F. W. Boulger, Supervising Metallurgist, Battelle Memorial Institute, Columbus, and R. C. Buehl, Chief Ferrous Pyrometallurgy Section, U. S. Bureau of Mines, Pittsburgh.

B. Use of manganese sulphide.

S. Feigenbaum, Assistant Metallurgist, Jones & Laughlin Steel Corp., Pittsburgh.

3. **Steel Bath Temperature Measurement:**

A. Advantages of knowing bath temperature.

B. Spoon test method and economics of same.

C. Bath immersion couple or spoon immersion couple.

Ralph Hindson, Works Metallurgist, Steel Co. of Canada, Ltd., Hamilton, Ont.

D. J. Carney, Chief Development Metallurgist, U. S. Steel Co., Chicago.

Oscar Pearson, Chief Metallurgist, U. S. Steel Co., Gary, Ind.

J. R. Brady, Supervisor, Research & Testing Dept., Wisconsin Steel Co., Chicago.

4. **Significance of the Furnace Block:**

M. Tenenbaum, Research Metallurgist, Inland Steel Co., E. Chicago, Ind.

NATIONAL OPEN HEARTH EXECUTIVE BOARD

6:00 pm — Rooms 566-68-70, Hotel William Penn

Dinner and business meeting of the National Open Hearth Steel Committee Executive Board.

TUESDAY, APRIL 1

9:30 am to 12:15 pm — Monongahela Room

COLD METAL SESSION AND BASIC FOUNDRY PRACTICE

Chairmen:

C. M. Kay, Superintendent Steel Works, American Steel & Wire Co., Worcester, Mass.

W. A. Peters, Metallurgist, Laclede Steel Co., Alton, Ill.

1. **Slag Control in Cold Metal Practice with the Use of Burnt Lime:**

W. H. Steinheider, Open Hearth Metallurgist, Sheffield Steel Co., Kansas City, Mo.

2. **Economics of the Use of Oxygen with Cold Charge:**

A. H. Sommer, Superintendent Steel Mills, Keystone Steel & Wire Co., Peoria, Ill.

A. Bigar, Jr., Research Engineer, Lukens Steel Co., Coatesville, Pa.

3. **Effect on Production of High Percentage of Pig Iron (+40 pct) in Cold Metal Practice:**

A. R. Edwards, Open Hearth Superintendent, Keystone Steel & Wire Co., Peoria, Ill.

4. **Progress Report Regarding Use of Bath Pyrometry in Basic Steel Foundries:**

Frank Hohn, Jr., Chief Metallurgist and Assistant Works Manager, Scullin Steel Co., St. Louis, Mo.

5. **New Method of Charging Open Hearth Furnaces:**

Albert Calderon, Materials Handling Engineer, Industrial Automation, Inc., 454 W. Alexandrine, Detroit

9:30 am to 12:15 pm — Ballroom

FUELS AND COMBUSTION

Chairmen:

J. M. Brashear, Open Hearth Superintendent, Lone Star Steel Co., Lone Star, Texas

Jack Dorman, Div. Superintendent Power and Fuel, U. S. Steel Co., Munhall, Pa.

1. **New Developments in Liquid and Combination Liquid and Gaseous Fuel Burners:**

W. H. Kahl, Open Hearth Combustion Engineer, Inland Steel Co., E. Chicago, Ind.

Discussion by E. T. W. Bailey, Chief Combustion Engineer, Steel Co. of Canada, Ltd., Hamilton, Ont.

2. **Future Trend of Sulphur Content of Fuel Oils:**

C. F. Kottcamp, Chief Fuels and Lubricants Engineer, Turbine and Steam Power Section, Industrial Products Engineering Div., Gulf Oil Corp., Pittsburgh

3. **Significance, Factors Affecting, and Methods of Measuring Preheated Air Temperature:**

H. S. Hall, Assistant Manager Combustion Control Dept., Morgan Construction Co., Worcester, Mass.

4. **Instrumentation:**

A. Automatic reversal—timing and how governed
B. Fuel—air ratio control
C. Successful roof temperature measurement

Lester Moore, Assistant Superintendent Open Hearth and Herman Meek, Combustion Engineer, Crucible Steel Co. of America, Midland, Pa.

R. A. Lambert, Superintendent Steam Efficiency & Combustion Dept., Jones & Laughlin Steel Corp., Pittsburgh

5. **Use of High Pressure Natural Gas for Atomizing Oil:**

L. D. Yager, Open Hearth Superintendent, Laclede Steel Co., Alton, Ill.

6. **A Method of Developing a Design of Furnace for Use of Natural Gas as Fuel:**

H. C. Barnes, Armco Steel Corp., Middletown, Ohio

7. **Effect of Uptake Dimensions on Furnace Performance:**

L. R. Berner, Superintendent Steel Production, Inland Steel Co., E. Chicago, Ind.

J. E. Hood, Assistant Open Hearth Superintendent, Steel Co. of Canada, Ltd., Hamilton, Ont.

2:00 pm to 5:00 pm — Ballroom

TRAINING OPEN HEARTH PERSONNEL

Chairmen:

L. R. Berner, Superintendent Steel Production, Inland Steel Co., E. Chicago, Ind.

H. E. Warren, Jr., Assistant General Superintendent, U. S. Steel Co., Morrisville, Pa.

1. **Visual Aids as a Tool for Training:**

A. Classroom instruction

B. On the job instruction

C. Methods and procedures used to improve quality of personnel by training, elimination of hazards, utilization of improved methods and mechanical equipment in the open hearth pit

D. Sound slide films—sample—problems—how used

L. G. Ekholm, Assistant Chief Metallurgist, U. S. Steel Co., Duquesne, Pa.

2. **Training Program:**

A. Melter foreman
B. First helpers
   a. Experienced
   b. New
C. Second helpers
D. Casting crews

M. F. Yarotsky, Superintendent Steel Production, U. S. Steel Co., Chicago

C. W. Conn, General Superintendent Ingot Production, Ford Motor Co., Dearborn.

E. E. McGinley, Chief Metallurgist, U. S. Steel Co., Youngstown

H. L. Tear, Open Hearth Superintendent, Jones & Laughlin Steel Corp., Pittsburgh

A. H. Osborne, Senior Open Hearth Metallurgist, Armco Steel Corp., Middletown, Ohio

3. **Effects of Foreign Ores as Open Hearth Charge Ore on Production Rates:**

A. Liberian ore

R. P. Carpenter, Open Hearth Superintendent, Republic Steel Corp., Cleveland

B. Moroccan ore

C. C. Benton, Assistant Superintendent Open Hearth, Tennessee Coal, Iron & R.R. Co., Fairfield, Ala.

WEDNESDAY, APRIL 2

9:00 am

VISIT TO PLANT

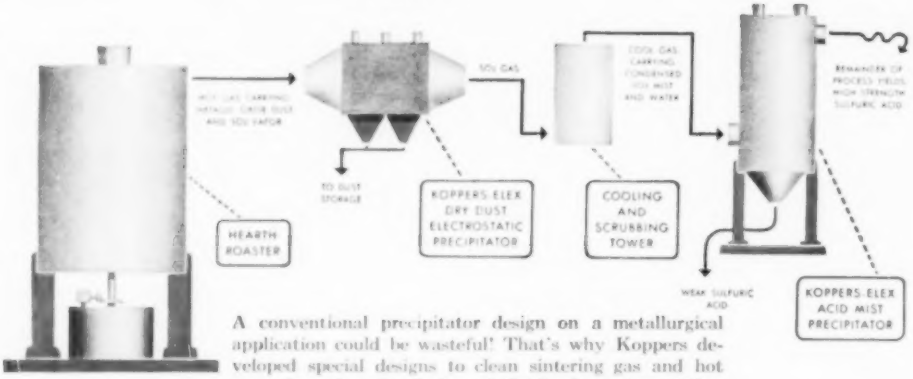
Plant Trip: Through the courtesy of the U. S. Steel Co., plant visits have been planned to both the Irvin and the Homestead district works on Wednesday, April 2. Transportation will be by means of a special train leaving the Pennsylvania Railroad Station at 9:00 am, arriving at the Irvin works at approximately 10:00 am. A trip has been planned through the Irvin works, to be followed by a luncheon. Visitors will board the train at 1:30 pm, arriving at Homestead works at 2:00 pm for a trip through the open hearth, 45 in. slabbing mill, and, if time permits, one of the finishing mills. The party will board the train at the Homestead works at 4:30 pm, arriving back at the Pennsylvania Station at approximately 5:30 pm.

For those interested in only the blast furnace operation, transportation will be made by means of a bus from the Homestead plant to its Carrie furnaces at Rankin, Pa.

An assessment of $2.50 will be made by the Blast Furnace, Coke Oven and Raw Materials and the National Open Hearth Committees to help defray the transportation cost and nontechnical Conference expenses.

Suppliers who have parlors for entertaining have been requested and are anxious to cooperate in closing their rooms during technical sessions and the dinner on Tuesday. Please help them cooperate by voluntarily leaving or avoiding their rooms at these times.

War on waste!



A conventional precipitator design on a metallurgical application could be wasteful! That's why Koppers developed special designs to clean sintering gas and hot gases from hearth, flash and fluidized roasters. Other types are also available for removal of acid mists.

Koppers-Elex Electrostatic Precipitators offer Guaranteed Rates of Recovery and Nuisance Abatement!

HERE'S THE RECORD*

Koppers engineers analyze each metallurgical gas cleaning and recovery problem individually. Then, based on extensive experience, they give you a specific recommendation of the amount of recovery that can be economically combined with the degree of gas cleaning you require.

A PROFITABLE INVESTMENT . . . that's the report about Koppers-Elex electrostatic precipitators on zinc roaster and acid mist applications. Not only is recovery guaranteed to any efficiency you specify . . . but proper engineering protects you against failure during overloads and production peaks!

Only Koppers gives you the drag scraper which provides continuous dust removal and eliminates plugged hoppers and bothersome dust build-up. Separately energized multiple series fields provide maximum collection of very fine particles . . . and protect your investment because outage of one field does not halt the gas-cleaning action of the precipitator!

Hundreds of Elex precipitators are in use today all over the world. Koppers-Elex electrostatic precipitators are designed, engineered, fabricated and erected under one contract by the Koppers Company . . . and each installation comes complete with "packaged" mechanical or vacuum tube power packs. If you have a gas-cleaning problem, write to: Koppers Company, Inc., Precipitator Dept., 264 Scott St., Baltimore 3, Md.

*Guaranteed: Koppers-Elex precipitators are guaranteed to equal or better (under tests made by your own personnel) any efficiency or residual content you specify.

KOPPERS

Koppers-Elex ELECTROSTATIC PRECIPITATORS

Panoramic view of blast furnaces at Ensley works, Tennessee Coal & Iron Div., U. S. Steel Co., Ensley, Ala.

Ensley's High Pressure Turbo-Blowers Increase Production Decrease Coke Rates

by J. J. Shannon

IT has been recognized and accepted by blast furnace operators that more iron could be produced by a given furnace if more air was blown within certain limits. This is based on the simple principle that coke burned per day will increase with increase in wind blown; and if the coke rate remains the same, increases in lower ratio, or decreases—then iron production will be increased. It has been widely accepted and firmly believed by many operators that an increase in the blowing rate arbitrarily increases the coke rate, and conversely, that a reduction in blowing rate will reduce the coke rate. This was seemingly confirmed by the *fanning* practices of the early 1930's. Efforts of engineers and operators therefore have been concentrated on producing iron at lowest cost by designing and operating furnaces to compromise on production per day and coke rate on a given size furnace, taking into consideration the items of investment, fixed cost per ton of iron, and cost of labor against cost of coke and materials.

With the war and postwar period the emphasis has shifted to production, with cost an important but lesser factor. A number of steel producers have purchased new blowing equipment as the quickest and cheapest way to increase production, and some have purchased high pressure blowers and used them in conjunction with high pressure tops. The general opinion of operators of high top pressure furnaces seems to be that they have increased production by blowing more wind, but coke rates have not improved materially. This opinion was expressed by R. P. Liggett[1] of Republic in his report on high pressure tops.

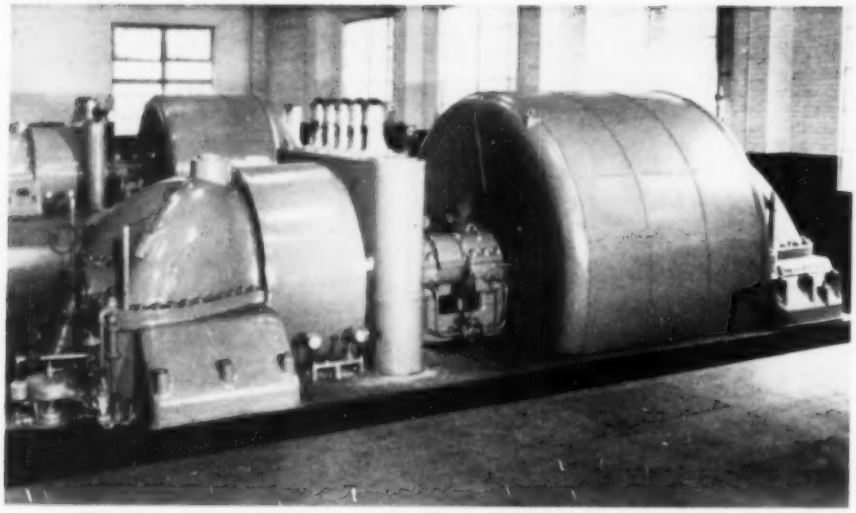
At Ensley, with the use of high pressure blowers, a marked increase in production rate and decreased coke rates have been attained. This is not attributed entirely to the high pressure blowers, but it is significant that without high pressure blowers full advantage would not have been made of some comparatively recent improvements such as conditioned ore, higher available blast temperature, and more available wind volume. All of these have tended to create more resistance to the flow of gases through the furnaces, resulting in higher operating pressures.

Tennessee Coal, Iron & Railroad Co. equipment, methods, and operating practices are, of course, designed to meet particular conditions and ores, and it is not claimed that they will work to the same extent with other ores and conditions. However, because of the depletion of high grade lake ores, blast furnace operators all over the country may be faced with similar problems in the coming years. Therefore, a discussion of the way these problems have been met may be of some benefit to all operators.

Ensley Furnaces and Equipment

Ensley plant has six blast furnaces. The first of three Ingersoll-Rand five-stage 100,000 cfm, 35 psi discharge pressure blowers was put in operation on No. 2 furnace Aug. 11, 1946. Two additional blowers of like capacity were put in operation May 6, 1949 on No. 1 and No. 4 furnaces. Experience with high pressure blowers has been confined to Nos. 1, 2 and

J. J. SHANNON is Superintendent of Blast Furnaces, Ensley Works, Tennessee Coal, Iron & Railroad Co., Ensley, Ala. This paper was presented at the Blast Furnace, Coke Oven, and Raw Materials Conference, Pittsburgh, Mar. 31 to Apr. 2, 1952.



Two of the turbo blowers serving the blast furnaces at Ensley works are shown here. Without high pressure blowers, full advantage would not have been made of recent improvements such as conditioned ore, higher available blast temperature, and more available wind volume.

4 furnaces, except for a short period when No. 4 furnace blower was used on No. 3 furnace, while No. 4 was out of blast.

Since results are influenced by furnace lines, volumes, and major auxiliaries, a brief description of the three furnaces is given. No. 1 furnace is a 22-ft hearth furnace with a working volume of 31,164 cu ft. It has 13 tuyeres, and 5 hot blast stoves with a total rated heating surface of 445,000 sq ft. No. 2 furnace is a 22½-ft hearth furnace with a working volume of 33,235 cu ft. It has 15 tuyeres, and 4 hot blast stoves, 2 with Freyn design 2-in. circular checkers, and a total rated heating surface of 516,000 sq ft. No. 4 furnace is a 22-ft hearth furnace with a working volume of 37,424 cu ft. It has 13 tuyeres, and 4 hot blast stoves, one of which has Freyn checkers, with a total rated heating surface of 493,000 sq ft.

No. 2 furnace is the superior furnace, both on production rate and coke rate. No. 4 furnace, in spite of its greater working volume, is limited by its small number of tuyeres. No. 1 furnace is limited by its tuyeres, and with a smaller working volume than No. 4 furnace, it tends to produce more flue dust when operated with higher blast volumes. It will be noted later that on No. 1 furnace, higher wind volumes, available since installation of the five-stage blower, have not been used to the same extent as on Nos. 2 and 4 furnaces for this reason.

Gas cleaning facilities consist of two Kinney tower washers and two Cottrell divided electrostatic precipitators. Tower washers are each designed for 100,000 cfm gas flow. The plant is capable of cleaning raw gas to a dust content of 0.01 grains per cu ft for blast furnace stove use.

The heating surface given per furnace is the design amount after completion of the stove rebuilding program that began in the spring of 1949 after completion of the gas cleaning facilities. Some stoves were rebuilt with Freyn design checkers and some had inserts installed. Stoves were put into service on a furnace as they were completed and considerable difficulty has been experienced with the insert stoves, with some being routinely off for repairs.

Table I. Average Production Data, Ensley Blast Furnaces

Year	Production, Net Tons per Month	Days Operated	Daily Production, Net Tons	Coke Rate, Lb per Net Ton	Blast Volume, CFM	Hot Blast Temp., °F	Flue Dust, Lb per Net Ton	Ores, Lb per Net Ton	Metal in Ore, Pct	Scrap, Lb per Net Ton	Metallics in Burden, Pct
				No. 1 Blast Furnace							
1940	21,008	234.58	896	2393	66,019	907	291	4955	38.30	187	40.25
1941	20,284	233.58	772	2462	65,003	918	241	4965	37.98	132	39.59
1942	24,057	268.00	831	2401	66,217	948	268	5056	38.67	110	39.80
1943	27,259	264.00	896	2284	66,925	1030	295	4950	39.56	107	40.67
1944	26,895	254.92	912	2048	63,878	1122	246	4806	39.55	108	40.96
1945	25,888	258.58	869	2135	63,452	1134	278	4941	38.41	151	39.98
				No. 2 Blast Furnace							
1940	24,666	259.17	857	2368	69,405	875	230	5004	38.52	205	40.25
1947	25,729	265.00	846	2309	66,867	856	152	4680	38.14	213	40.50
1948	24,204	260.00	862	2279	67,186	886	210	4824	38.40	167	40.07
1949	29,609	264.42	979	2102	70,379	979	187	4750	39.27	175	41.03
1950	30,040	261.50	1042	1961	69,885	1116	210	4529	39.28	192	41.96
1951	31,016	272.43	1076	2047	75,328	1159	246	4851	38.84	160	40.52
				No. 4 Blast Furnace							
1946	22,901	249.20	830	2347	66,622	904	289	4918	38.32	171	40.08
1947	24,394	260.00	892	2368	64,950	911	272	4884	38.35	153	40.01
1948	23,451	241.25	735	2546	65,392	1009	309	5090	38.30	112	39.44
1949	20,663	188.42	764	2363	65,348	984	375	5129	38.88	127	40.27
1950	20,672	247.75	1015	1956	67,765	1151	193	4724	39.62	126	40.96
1951	20,851	256.00	972	2002	69,543	1166	212	4822	38.42	156	40.09

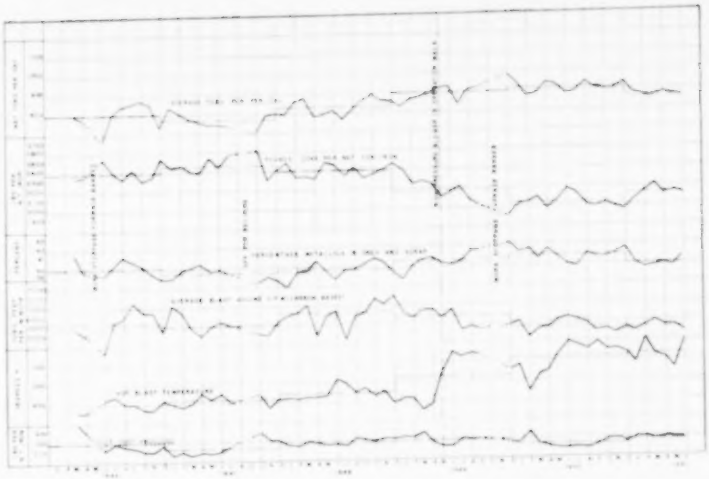


Fig. 1—The use of higher blast heats on No. 1 furnace reduced the coke rate, resulting in a higher daily production. When the five-stage blower was put in operation, an additional 200 F hot blast was used.

Design heating surface therefore has not been available on all furnaces for extended periods. This is reflected in the results. Fluctuations in the hot blast temperatures largely reflect the stoves available and were not entirely controlled by the operators.

Results

Table I and Figs. 1, 2, and 3 show average monthly and yearly data covering a period of the last 5½ years through June 1951 for furnaces Nos. 1, 2 and 4. The charts indicate in general the extent to which production has increased and coke rates have improved. Other correlated data which have a pronounced effect on production and coke rates also are shown.

Fig. 1 is a graph of the more important data on No. 1 blast furnace. It will be noted that at the same time that the five-stage blower was put in operation, additional hot blast temperature of about 200 F was used. This additional blast temperature, which had been available for a short time before blower was put in operation, could not be used previously because of its tightening effect which resulted in pressure against which the four-stage blower could not blow effectively.

The major improvement noted on this furnace is the lower coke rate and higher blast temperatures. This furnace operates under the highest pressure of the three furnaces, probably attributable, as noted before, to limitations of furnace design, and the volume of wind blown had to be reduced after the installation of the high pressure blower. It will be seen, however, that using higher blast heats reduced the coke rate, and the lower coke rate resulted in a higher daily production even though blast volume was decreased.

Fig. 2 is a similar graph for No. 2 furnace. The first five-stage blower began blowing this furnace in August 1946 and the improvement was immediately apparent. The first four months on the new blower showed record tonnages and coke rates. It was estimated at that time that production was increased,

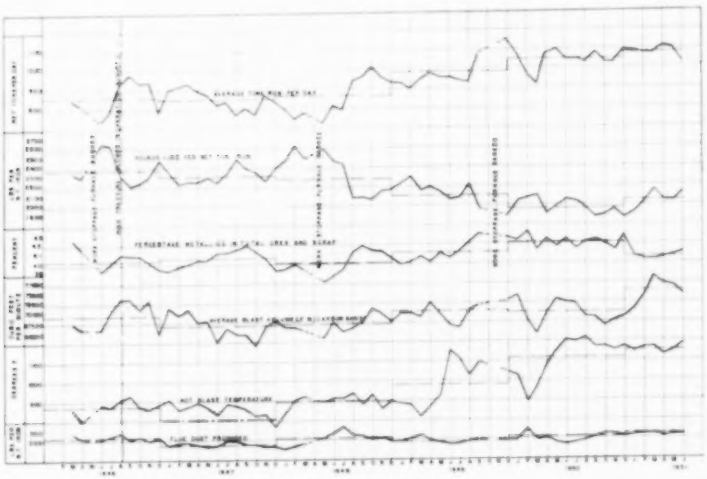


Fig. 2—Record tonnages and coke rates were obtained on No. 2 furnace during the first four months that the five-stage blower was used. Production was increased by 85 tons per day, and 200 lb coke was saved per ton of iron.

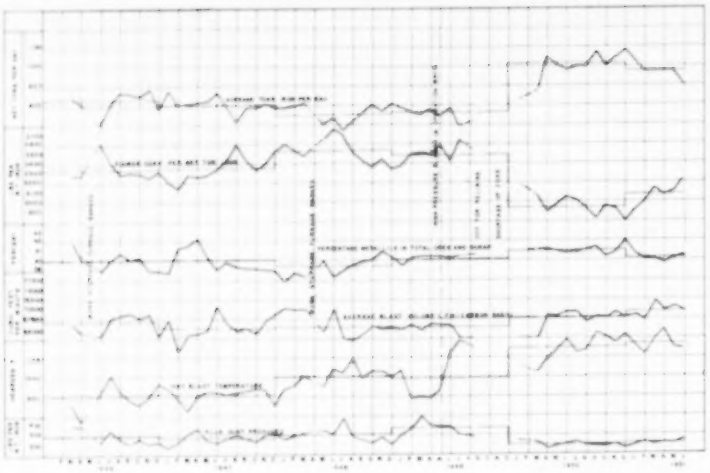


Fig. 3—No. 4 furnace did not show improvements with initial use of the five-stage blower because of the condition of the furnace lining. After relining in March 1950, a marked increase in tonnage and improvement in coke rate was noted.

after correcting for metallics in ores, scrap charged, etc., by 85 tons iron per day and 200 lb coke saved per ton of iron. This furnace was nearing the end of its campaign on that lining and production tapered off until the furnace was rebuilt during the coal strike of 1948. The furnace was returned to operation before the stove work was finished, but as more hot blast heat became available, production and coke rates improved to new record levels.

Fig. 3 is a similar graph for No. 4 furnace. The five-stage blower was put in operation on No. 4 furnace two months prior to the time this furnace was taken off for relining. Even though more blast temperature was available this furnace did not show improvement in tonnage and coke rate for this short period possibly because of condition of furnace lining. On resumption of blast in March 1950 a marked increase in tonnage and improvement in coke rate was noted for the remainder of the period.

The data used in these charts is the routine accounting monthly averages with no correction made except for the deletion of months in which abnormal operations were experienced because of strikes, shortage of materials, etc. Since furnace operations are affected by many factors which are not subject to rigid control such as condition of furnace lining, physical characteristics of ores and coke, etc., and because normal operations fluctuate widely even when no apparent changes are made in controllable items, an examination of furnaces that operated under similar conditions with four-stage blowers is illuminating.

No. 3 Ensley blast furnace is a 19½-ft hearth furnace with 12 tuyeres and the same working volume as No. 1 furnace. It has stoves similar to No. 4 furnace with heating surface of 493,000 sq ft. Prior to the installation of the last two five-stage blowers, this furnace was blown with a 72,000 cfm blower in conjunction with two or three blowing engines. After the new turbo-blowers were in service this furnace was blown with an 85,000 cfm, 30 psi, four-stage blower. This was believed to be ample blowing capacity for this furnace, but results were disappointing as coke rates remained about the same—approximately 2375 lb, and production rates increased only from approximately 775 to 790 net tons per day.

In December 1949 and January 1950 while No. 4 furnace was out of blast, No. 3 furnace was blown by No. 4 five-stage blower. During these two months this furnace established new records for coke and production rates. Coke rates averaged 2072 lb for the two months, and production rate was 884 net tons per day. This was an improvement over the previous six months on the four-stage blower of 181 lb of coke and 98 net tons iron per day. Since that time, although every effort has been made to favor this furnace with scrap and ores, it has averaged only about 800 net tons iron per day, and coke rates have been 200 to 250 lb higher than No. 1 furnace.

Nos. 5 and 6 Fairfield blast furnaces are identical furnaces with 23-ft hearths, 16 tuyeres, 40,101 cu ft of working volume, and have four stoves each with total heating surface of 428,400 sq ft per furnace. Fairfield is the newer and more modern plant with all facilities and auxiliaries equal to or better than those at Ensley with the exception of the blowing equipment. The ores and coke used are from the same source, and the practice at the two plants is essentially the same. Prior to the Ensley modernization program, the Fairfield coke rates averaged approximately 75 lb per ton less than comparable furnaces at Ensley. The coke rates on these two furnaces for a comparable period are given in Table II.

Thus it can be seen that there was no corresponding improvement in coke rates at Fairfield Nos. 5 and 6 furnaces. Fairfield No. 7 furnace also showed no improvement in 1949 vs 1945 to 1946. Data is not given since it was rebuilt and enlarged in 1949 and the figures are not comparable.

Production rates for 1950 and 1951 for Fairfield Nos. 5 and 6 furnaces and Ensley No. 2 furnace are shown in Table III.

It has been concluded that with no major change except in blowing power permitting the use of higher blast temperatures, Fairfield Nos. 5 and 6 would exceed the results obtained on No. 2 Ensley especially in view of the greater number of tuyeres and larger furnace size.

In the standard cost accounting system budgets are routinely corrected for all major items which affect production and coke rates. For the purpose of measur-

ing the improvements on an adjusted basis, selected normal months in 1945 and 1946 were averaged to give a normal base production and coke rate before modernization. This base was adjusted each month to the actual metallics in ores, amount of scrap charged, moisture in blast air, carbon in coke, and bases and acids in the ore and coke. Table IV gives the results for the 12 months, during which the entire improvements have been available to date, July 1950 through June 1951.

The adjusted improvement for the three furnaces is thus 430 addifional tons of iron per day and a saving of 284 lb of coke per ton iron.

This part of the discussion is an attempt to rationalize results by established chemical, physical, and thermal principles. This is better than the usually unpleasant position of trying to explain why some excellent theories do not give good results. A complete and detailed study of such a complex subject cannot be presented here. The aim is merely to present a point of view with only occasional resort to numerical values.

Table II. Coke Rates of Fairfield Furnaces

Year	Lb per Net Ton of Iron	
	No. 5 Furnace	No. 6 Furnace
1945	2372	2299
1946	2359	2310
1949	2197	2295
1950	2363	2279

It is believed the results obtained can be attributed to four causes: 1—The effect of conditioned ore burden; 2—the effect of driving practice; 3—the effect of blast temperature; and 4—the effect of pressure.

These effects, of course, are interesting and a change in one usually produces a change in one or all of the others. However, for convenience they will be taken up separately and then the overall effect will be considered.

Effect of Conditioned Ore Burden

Nearly all ores used at Ensley, mainly Red Mountain hematites, but with small percentages of native brown ore (limonites) and foreign ores, are crushed, screened to size, and blended at a central ore conditioning plant erected for that purpose on Red Mountain in 1940. The ores are crushed and separated into two sizes; coarse, 13/16 to 1½ in., and medium, 3/8 to 13/16 in. The −3/8 in. fines are mixed with flue dust and sintered on continuous type down draft machines. Crushing is varied slightly to try to maintain a blast furnace filling of approximately 50 pct coarse ore, 25 pct medium ore, and 25 pct sinter.

Prior to 1940, ores were crushed at the mine tipple to a maximum size of about 4 in. and charged into the blast furnaces with or without the screening of fines. The Red Mountain ore is a very hard dense hematite of low porosity and was difficult to reduce in the large sizes. However, even when fines were charged, it gave a relatively open burden. With the finer ore burden, after conditioning was begun, pressures increased even with the same blast volume. It was found that with the more rapid reduction allowed by the better preparation of the ore, more wind could be blown and coke rates were reduced.

This combination of tighter burden and increased volume of wind raised the blast pressure about 4 or 5 psi, and loaded existing turbo-blowers to about the limit of their capacity. This led to operating difficulties and irregularities which could be overcome by high pressure blowers of greater capacity. Thus limited blowing capacity prevented the realization of the possible benefits of finer sized ore and part of the improvements noted are accounted for by removal of this limitation.

Table III. Production Rates for Fairfield Furnaces

Year	Avg. Net Tons Iron per Day		
	Ensley No. 2	Fairfield No. 5	Fairfield No. 6
1950	1042	918	943
1951 (6 months)	1076	879	903

Effect of Driving Practice

The outstanding difference in southern and northern blast furnace practice, excepting raw materials, is the forced descent of the stock by periodically reducing the wind volume and pressure as practiced in the south. This method has been used continuously at Ensley since 1904 and earlier, and perhaps originated at this plant since it was not in common use at other southern blast furnace plants as late as 1918. Because of the low iron content of southern ores (37 pct) and the necessary high coke rates, the bulk density of southern burdens is too low to maintain *free travel* against the uprushing gases where the pressure drop exceeds 12 to 15 psi. By the simple expedient of slackening the wind at intervals and letting the stock travel in short steps rather than a continuous downward movement, greatly increased blowing rates with resulting higher production rates were made possible.

The practical limit for blowing rates with present practice on northern furnaces is the limit at which the stock will descend freely without hanging and slipping. The actual blowing rates are well below the limit in order to maintain regularity of operation and a margin of safety since the increase in blowing rate has a cumulative effect against free descent of the stock—an increase of 10 pct in the blowing rate requires an increase of 10 pct in stock descent rate, and the pressure drop through the stock, which is the main uplifting force, will usually increase much more than 10 pct.

By contrast, in southern practice no counter current action need be maintained and the theoretical limit is the rate at which stock will be blown out of the furnace. The actual limit is the amount of wind that is available and the pressure against which vol-

Table IV. Improvements in Production and Coke Rates at Ensley

Furnace	Actual	Adjusted Base	Improvement
Production Rate, Net Tons Iron per Day			
No. 1	891	819	72
No. 2	1061	842	219
No. 4	1003	864	139
			Total 430
Coke Rate, Lb per Net Ton Iron			
No. 1	2079	2330	251
No. 2	1969	2277	308
No. 4	2006	2238	232
			Avg. 284

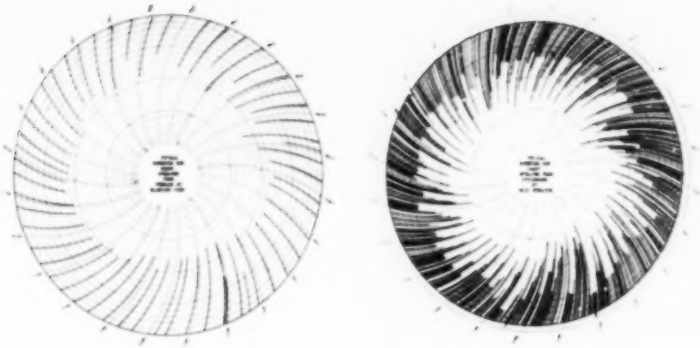


Fig. 4—The sounding rod chart at left is typical of stock movement at slack time. The chart at right is of stock level as shown by the stockhouse rod.

ume can be maintained, and the amount of flue dust loss that can be tolerated. Regularity of furnace operation easily is maintained by this method almost regardless of the volume of wind blown.

The descent or movement of the stock is limited to short downward steps by varying the frequency of the slack—more frequent slacks at higher driving rates and vice versa. The importance that operators attach to regularity even though achieved by opposite methods, is illustrated by the practice at one of the independent companies in this district, where free travel of the stock is avoided, if possible. If the stock moves between slacks at this plant, steps are taken to prevent it as stock movement is deemed desirable only at the prescribed intervals.

The practice at TCI is to reduce wind volume and pressure at regular intervals, usually 25 to 35 min, by opening the snort valve, and if necessary, checking the turbo-blower to lower pressure, until stock moves. Stock sounding rods do not ride the stock but are lowered periodically to check stock level. Fig. 4 exhibits typical sounding rod charts showing the movement of stock at slack time on one rod and the stock level as shown by stockhouse rod. Fig. 5 shows pressure charts on high pressure blowers. No attempt is made to stop the travel of the stock between slacks, but normally more than 50 pct, and at times 100 pct, of the movement is obtained by checking air volume. This practice is followed not only for basic iron using native ores, but also on the high iron, finely divided sintered ores of ingot mold burdens.

This innovation is not an unmixed blessing where blowing equipment is inadequate, since in blast furnace practice it usually is impossible to change one thing without affecting another. In this case the increased wind volume and the *jamming* of stock in the bosh both work to increase the normal pressure at which the furnace operates. This was true even prior to 1940 when the furnaces were operated on lump ore and an open burden and was accentuated by the use of the much smaller particles of the conditioned burden. It is not meant by this statement that pressure itself is harmful, but where blower capacity is low compared to furnace size, the blower drops its volume as the pressure approaches the limit and the furnace becomes even tighter with the decreased wind, and it may be hours or longer before normal operation can be resumed.

With the use of high pressure blowers the furnace will work itself off excess pressure and continue to make excellent coke and production rates. An illustration of this is shown by the pressure charts in Fig. 5. In the left hand chart the pressure is jumping up after slack but comes back down before the next slack as the blower *bucks* the pressure and opens the burden. The furnace is moving easily as the pressure only has to be lowered to 20 or 25 lb to make the furnace move. In the right hand chart pressure is building up to peaks before the slack and moving is more difficult. The significant point is that, because of the high pressure blower, furnace

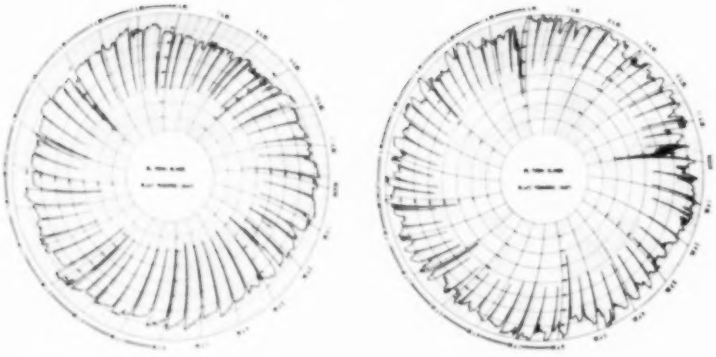


Fig. 5—The furnace moves easily when pressure decreases between slacks, as the blower bucks the pressure and opens the burden, as shown in the chart at left. In the chart at right, the pressure builds up to peaks before slack, and moving is difficult.

operation was uninterrupted and excellent coke and production rates were maintained.

The other obvious disadvantage to this practice is the lost blowing time in slacking a furnace 50 or 60 times per day. This is more than overcome by the higher blast rates made possible. Further, the wind volume lost by slacking is not as great as it seems since pressure can be reduced in much greater ratio than volume—that is a 50 pct decrease in pressure will only decrease the volume 25 or 30 pct.

Effect of Blast Temperature

Blast temperature performs two important functions: 1—It facilitates the attaining of high temperature in the hearth zone, and 2—it supplies heat units without producing gas as a byproduct.

The first function of producing heat intensity is understood and appreciated by all operators. Blast furnace operation is not feasible if the iron and slag are not above the critical temperature (the free running temperature) where it will run out of the furnace and into the ladles. Blast furnace men have all but sweat blood over a cold furnace trying to work coke down into the hearth to get the hearth back to proper temperature. It hardly is surprising then that blast furnace operators have longed for stoves that could furnish them with 1500°F hot blast to help them out of trouble. It has been a rather bitter experience for engineers and top management to build stoves which will straight line 1500°F and then find the operators day after day using only 1000°, 900°, or 800°F. It also has been the frustrating experience of the operator to cut the burden as low as he dared, run the blast heats up to 1100° or 1200°F and then see pressure run up until the pop valve stays open, the furnace slip and roll, and its driving stop completely.

The answer to this conundrum seems to be that too much of a good thing can be had as far as temperature is concerned, and if the work done before the tuyeres is confined to the melting of the iron and slag and removal of impurities, too high a temperature is obtained in the hearth, and correspondingly the temperature gradient above, so that the ore and gangue become sticky and viscous well up in the bosh and perhaps even into the stack. These objectionable effects of high blast temperature are not experienced where magnetites or sinter are used. Much higher temperatures can be carried in the summer months even on furnaces that do not have high pressure blowers. In these cases the heat carried into the furnace by the blast is used to dissociate the moisture or for solid direct reduction of ores. Since these are strongly endothermic reactions, the heat is absorbed in the lower bosh without the undesirable effects higher in the furnace.

The question as to the value or desirability of direct reduction has been debated by blast furnace men since the turn of the century with no agreement. It would seem that results in recent years, where furnaces on special tests or in routine operations have bettered the fuel economy of the so-called ideal or perfect furnace operation of Gruner[2] or Austin,[3] apparently only by having large percentages of direct reduction, would be convincing proof that a new ideal or standard method of furnace operation is needed.

The chemical principles of direct reduction are simple enough as shown in the equation for solid reduction of hematite:

$$Fe_2O_3 + 3\,C \rightarrow 2\,Fe + 3\,CO \quad (-4111 \text{ Btu per lb oxygen})$$

The CO gas formed will perform the same functions of reduction as the CO gas formed by combustion of carbon with air and will tremendously reduce heat losses since the volume of gas produced per pound of metal reduced is approximately 1/12 the volume of gases per pound of metal reduced by indirect reduction by air and carbon. Further reduction by the CO gas at the approximate equilibrium ratio of CO_2/CO of 1:1 gives

$$1/2\,Fe_2O_3 + 3\,CO \rightarrow Fe + 1.5\,CO + 1.5\,CO_2 \quad (+263 \text{ Btu per lb oxygen})$$

or at the good actual furnace practice of CO_2/CO of 2:1

$$1/3\,Fe_2O_3 + 3\,CO \rightarrow 2/3\,Fe + 2\,CO + CO_2$$

The summation of the two equations

$$Fe_2O_3 + 3\,C \rightarrow 2\,Fe + 3\,CO$$
$$1/3\,Fe_2O_3 + 3\,CO \rightarrow 2/3\,Fe + CO_2 + 2\,CO$$

shows a possible carbon rate for a net ton of iron (96 pct Fe and 4 pct C) of 543 lb or in terms of TCI coke, a coke rate of 630 lb. This, of course, is only the coke required by the chemical process and a net additional source of heat of about 2,500,000 Btu per ton of iron reduced by this method is required.

High hot blast temperature is certainly a source for this required heat, and blast heat so utilized would furnish tremendous fuel economies as has been demonstrated by P. V. Martin.[4] The saving in fuel is accumulative—because the more direct reduction, the less air is required, and the less heat is lost to top gases both in sensible heat and as fuel in the form of CO to satisfy the equilibrium requirements. Obviously though, the amount of direct reduction possible is limited since less air required means less heat brought in per ton of iron even though the blast temperature could be increased without limit. A proper balance between direct and indirect reduction is the most economical.

The possible economies can be seen by a few simple calculations. If a furnace is operating efficiently at Gruner's ideal, with all reduction taking place high in the furnace and the hearth doing only refining and melting, at a coke rate of 1400 lb per ton iron, if an additional 625,000 Btu per ton iron is put in by the hot blast and brings down 25 pct of the ore to be reduced by solid carbon in the hearth, the resulting coke rate would be 1210 lb per ton of iron. This rate has been approached in several test runs on large American furnaces. It is suggested also that it would be impossible to make the furnace take the additional blast temperature without serious operating difficulties unless the heat is absorbed by solid reduction or other heat absorbing reactions before the tuyeres.

This concept perhaps explains why the operators using eastern or foreign magnetites, use blast temperatures of 1500°F and wish they had 2000°F, and the Chicago district operators with excellent coke rates find it difficult at times to use even 1000°F.

Of course Gruner's ideal is not even approximated on Ensley furnaces. However, because of the high CO_2/CO ratios in top gas probably all reduction was

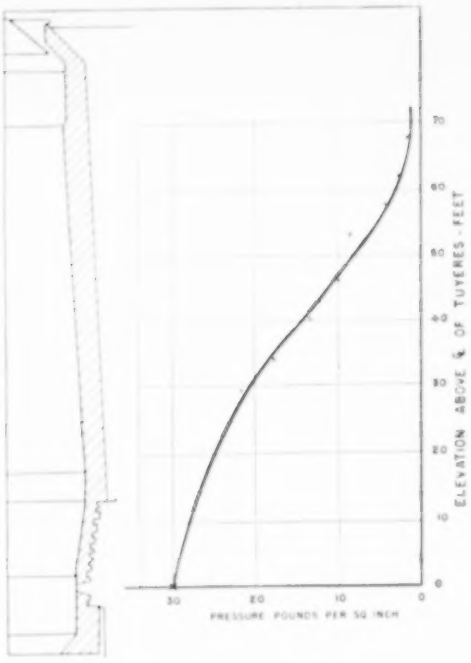


Fig. 6—The major portion of the pressure drop is in the upper portions of the stack, as can be seen from this chart of actual pressure drops through an Ensley furnace operating at normal pressure of 30 psi.

previously done well above the tuyeres. This observation is perhaps substantiated by the experiments of Kinney[5] who found that 80 pct of the ore was reduced at the mantle on a southern furnace as compared to 24 pct on a northern furnace using Mesabi ore. Solid reduction of part of the ores and less top gas produced, therefore, offer the same possibilities of improved fuel rate, and are probably a significant portion of the actual improvement noted in results with the high pressure blowers.

Effect of Pressure

To most blast furnace men pressure is just something that is necessary for blowing wind through the stock in a furnace and it is considered neither good nor bad unless the pressure gets too high and the furnace *slips* and *rolls*.

The blast furnace therefore has been operated as a pressure vessel by necessity and only in recent years has there been any deliberate attempt to raise the pressure of the process. Indirectly, however, nearly every improvement in blast furnace operation since the days of the stone furnace, blown by a water powered leather bellows or a trompe, has been accompanied by an increase in furnace pressures. A very impressive statistical correlation therefore exists between average furnace pressure and both production rates and fuel economy. This correlation is very marked between average pressures on different furnaces but is much less so as regards different periods on the same furnace. This inconsistency can be explained by saying that pressure is desirable as long as good gas-solid contact is maintained, and as long as the pressure is neither accompanied by, nor is the result of, *hanging*, *slipping*, *rolling*, or other furnace operating difficulties.

Average blast pressures at Ensley over the past ten years have risen from 18 to 22 psi, to 28 to 32 psi. This increase is attributed to: 1—Use of conditioned or finer crushed ores and sinter; 2—higher blast volumes; 3—higher blast temperatures; and 4—the practice of moving the stock by *slacking* wind.

Average top pressures have remained about 2 lb and thus the average pressure drop through the furnace has increased about 10 lb. A check of the actual pressure drops through an Ensley furnace operating at normal pressure of 30 psi is shown in Fig. 6. It can be seen that at Ensley the major portion of the pressure drop is in the upper portions of the stack. The bosh and lower stack pressures thus have been raised nearly the whole 10 psi overall increase.

This increase in pressure is believed beneficial on furnaces where high pressure blowers are used and regularity of operation can be maintained. The increase in pressure from approximately 20 psi to 30 psi increased the density of bosh gases by 30 pct, decreased gas velocity by the same amount, and increased the time the gases were retained in the furnace.

An examination of the theoretical aspects of higher pressures in the combustion zones of blast furnaces leads to the conclusion that increased pressure facilitates the attainment of higher temperatures with less fuel, and resulting benefit to the furnace economy.

Summary

Since the installation of high pressure, five-stage turbo-blowers at Ensley, production rates have increased and coke rates have improved. On a comparable basis it is estimated that the three new blowers have increased production by 430 net tons of iron per day with a corresponding decrease in coke rates of 284 lb per net ton of iron. Although the extent of the improvement has varied from furnace to furnace, all furnaces that have been blown with the high pressure blowers have shown significant improvement. During comparable periods furnaces blown with four-stage blowers have not exhibited similar improvement.

It is thought that part of the improvement is caused by higher pressure being beneficial, especially in the combustion zones or lower regions of the furnace. Higher pressure probably reduces the heat requirements of the hearth by heat compression which makes a higher temperature available in the hearth with less fuel, which along with higher blast temperatures, makes available heat that can be utilized by direct reduction of ores that are brought down unreduced by the faster driving of the furnace. In addition the higher pressures available from the new blowers made possible the full use of other improvements which tend to raise furnace pressures.

References

[1] R. P. Liggett: Pressure Operation of Blast Furnaces. Chicago regional meeting AISI, 1950.

[2] M. L. Gruner: Blast Furnace Phenomena. 1874 H. C. Baird Co.

[3] J. B. Austin: Efficiency of the Blast Furnace Process. *Trans.* AIME (1938).

[4] P. V. Martin: Effect of the Solution Loss Reactions on Blast Furnace. *Trans.* AIME (1939).

[5] S. P. Kinney: The Blast Furnace Stock Column. *U.S. Bur. Mines*—T.P. 442 (1929).

Manganese: Sources and Beneficiation

RUSSIA was the United States' Number One source of manganese ore in 1948 when 34 pct of imports were received from that source, stated Norwood B. Melcher, assistant chief, ferrous metals and alloys branch, Bureau of Mines. In 1949, this country received only 20 pct of 1948 shipments from Russia, and only token amounts are now being received. Aggressive programming by industry and government resulted in prompt increases in shipments from major producing sources; India, Gold Coast, and the Union of South Africa all increased exports to fill the vacuum left by Russia and provided an excess adequate to increase total imports approximately 290,000 short tons in 1949. Again in 1950, and with even less ore from Russia, imports increased another 290,000 short tons. Since the shift from Russia as a source of manganese, the United States has received in total about 85 pct of its imports from India, Union of South Africa, Gold Coast, and Brazil in that order of importance.

Producers of both home-consumed and merchant ferromanganese have been able to adjust downward the manganese content of the home-consumed product and so obtain partial relief. Millions of tons of steel were produced in 1951 with a relatively low grade ferromanganese. This adjustment has been made without decreasing the quality of the steel, although with some increase in cost through introduction of new problems, including increased handling of material and additional removal of carbon.

Forced into a pattern of price and grade structure such as exists today, the producer of ferromanganese must adopt one of three possible courses as a short-range program: 1—He may continue to deplete his stocks by producing standard (78 pct) ferromanganese and hope that the future will bring some form of relief; 2—he may attempt to produce 78 pct ferromanganese by paying higher prices for premium ores; or 3—he may drop the grade of ferromanganese and stretch stocks and future supplies of ore as far as possible.

The present rundown condition of Indian railroads is attributed to the fact that the service has had no opportunity to recuperate since the beginning of World War II, while the demand for the movement of commodities has probably increased.

The Union of South Africa has expanded its exports to the United States greatly since 1948, but the showing of that country in 1951 was disappointing. Efforts have been made for some time by firms in the United States, at the urging of the manganese miners in the Union, to prevail on the railroad authority to grant and make available larger allocations of cars for manganese ore movement. As a whole, such efforts have been unsuccessful. Although the allocation of rail shipping has been the obvious factor in the decreased movement of ore, many other less determinate factors appear to be involved.

Brazil, long an important supplier of manganese to the United States, has important manganese deposits in three areas, all of which are significant to this country.

The Gold Coast is an important source of supply. Its metallurgical ore is particularly of significance because of its unusually high grade which permits considerable latitude in blending with the lower grade materials of South Africa and India.

The Belgian Congo should have an output of 100,000 tons or more annually beginning this year.

R. S. Dean presented two papers. One with K. M. Leute on hydrometallurgical methods for recovery of manganese from domestic ores and one as sole author on the so-called *carbamate* or Dean process. The two papers tied into each other. In the first mentioned he reviewed the various processes applicable to oxidized, and nonoxidized and reduced ores. The advantages of each were pointed out.

So far the only process tried on a substantial scale on oxidized ores was the SO_2 process used at Las Vegas, Nev., on Three Kids ore during World War II. Many problems were encountered. Some of them were whipped while some of those remaining perhaps would have been whipped had time permitted. Since then work has been done elsewhere to avoid the formation of the troublesome thionates encountered at the Three Kids plant. Dean discussed the thionate and NO_2 processes as applied to oxidized ores.

The only commercially used process on reduced ores is that of making electrolytic manganese. Among others that have been considered are the nitric acid process, the Bradley-Fitch ammonium sulphate process, and Dean's ammonium carbamate process.

Dean's thesis was that extremely large tonnages of so-called low grade manganese ores are available, and that these should not be depleted in attempting to simulate a foreign metallurgical grade ore. He pointed out that the grade of the domestic manganese ores would be considered high if the same grade were found in copper ores. The selling price of electrolytic manganese and electrolytic copper are roughly the same.

In addition to electrolytic manganese, he believes that domestic ores should be used to make exceptionally high grade products. These might be battery grade oxide or substantially pure oxide sinter, which might be used for high manganese alloys or for upgrading metallurgical grade manganese to produce a high manganese ferroalloy.

The carbamate process is based on the fact that manganous oxide is readily soluble in concentrated ammonia solutions containing ammonium salts. In solutions of sufficiently high concentration the manganese exists as an anion. Lixiviants of ammonia and ammonium carbonate permit extraction of the manganese from reduced ores and the manganese can be recovered as carbonate by heating or by driving off ammonia.

R. V. Lundquist presented a paper on upgrading high-silica ores or concentrates with sodium hydroxide to extract silica and to yield a product with a more favorable manganese : silica ratio. The NaOH is regenerated in part by CaO.

This timely session held on Tuesday morning, Feb. 19, 1952 at the AIME Annual Meeting was sponsored jointly by the Extractive Metallurgy Div. and the Minerals Beneficiation Div. J. H. Jacobs, U. S. Bureau of Mines, Boulder City, Nev., and John D. Sullivan, Battelle Memorial Institute, Columbus, were Associate Chairmen.

Conserve Diamond Bort And Cut Hard-To-Machine Materials

With New Machining Processes

With the conservation of diamond bort of special interest, potential values of new processes for machining and grinding have been evaluated by the Minerals and Metals Advisory Board of the National Research Council. This abstract was prepared directly from their report.

DIAMOND wheel grinding has for some time been the only practical method for shaping and finishing cemented carbide tools and tungsten carbide projectile cores. These job items account for approximately 70 pct of the diamond bort consumption in this country. At the present time, imports and reclamation of diamond bort are limited and although there may be some increase, these might not be sufficient to produce the tools and military end items in the event of a substantially increased preparedness or mobilization program. In addition, many new military items, which involve hard-to-machine materials, are being developed, and the anticipated rate of production of these is very large. This will make the diamond bort procurement situation even more serious.

Therefore, there is a need for the development of new processes that do not require diamond bort. The basic phenomena of several such processes are known, but their status with respect to specific important applications must be evaluated. Descriptions of these new techniques and evaluation of their potential values with respect to these important operations or job items is the subject of this report. Also, some conclusions have been reached on the direction of research and development to bring these processes as rapidly as possible into large scale industrial testing use. These conclusions are based on understandings resulting from a panel meeting held Dec. 12 to 13, 1951, in Washington, D. C. Members of this panel included scientific and technical specialists in the fields of grinding, machining, electrochemistry, and cemented carbides.

New Processes

Excluding various ramifications of methods employing bonded or coated abrasives, there are known to be several processes under development in this country which might be substitute methods for diamond wheel grinding operations or have possibilities for machining and grinding hard-to-machine materials that are badly needed for our preparedness program. These techniques include 1—the electrolytic process, 2—the electro-sparking process, 3—the electro-arcing process, 4—the ultrasonic process, and 5—various combinations of the preceding four.

The following summarizes the essential descriptions and features of each of the processes, as currently practiced or being developed in the United States. Similar processes are being developed abroad.

Electrolytic—Electrolytic grinding is usually performed by a revolving metal disc cathode in close proximity to an anodic workpiece while an electrolyte is applied to the disc and workpiece in the same manner as a coolant is applied to a grinding wheel and work. The method is usable for removing stock from electrically conducting bodies such as metals or metal carbides. It appears especially suited for removing stock from large surfaces, but its applications are limited where very small surfaces need be ground or for drilling of small diameter deep holes.

The electrolytic process utilizes steady direct current and a highly conducting electrolyte. Relatively low voltages of less than 25 v and usually between 16 and 18 v are used. It is characterized by low local heating and essentially no consumption of the cathode. In this process a true electrochemical action

Table I. Important Machining and Grinding Operations and Estimated Applicability of Methods

Job Item or Operation	Use of Diamond Bort,** Pct	Diamond Wheel Grinding	Applicability of Methods*			
			Electrolytic	Electrosparking	Electroarcing	Ultrasonic
Sharpening of single point tools	30	A	B	B***	C	B***
Grinding single point tool chip breakers	20	A	B	B	C	B
Sharpening milling cutters and broaches	15	A	B	B	C	B
Grinding projectile cores	5	A	B	B	C	B
Shaping and finishing dies	4	A	D	A	D	A
Forming of turbine bucket attachments	—	B	B	B	C	B
Rifling of gun barrels	—	B	C	B	C	B
Machining and grinding of compressor discs	—	B	B	B	C	B

* A—In use on production scale.
B—Appears applicable; promising but limited experimental data to date.
C—Questionable applicability; not promising but might be developed to be promising.
D—Limited applicability or not applicable; not usable in present state of development.

** Approximate percentage of total diamond bort currently being consumed in the United States. All diamond wheel grinding consumes about 85 pct of the bort and the operations considered account for 75 pct of the bort. The remaining 10 pct is used for a multiplicity of operations.

*** Not applicable for off-hand grinding but appears applicable for machine grinding.

takes place in accordance with Faraday's Law. With fixed current density, the rate of stock removal, in terms of volume per unit of time, is proportional to the effective area of the work exposed to the electrolytic action. Cathode-anode spacing and polarization effects appear to be critical factors in the electrolytic process, particularly for shaping or finishing cemented carbides.

Electro-Sparking Process—In the electro-sparking method, stock is usually removed by making the work one of the electrodes in a properly designed circuit. Rapidly pulsed current (usually oscillatory) of the spark discharge type is passed between the work and the other electrode in a dielectric fluid. The method is used for removing stock from electrically conducting bodies such as metals or metal carbides and is especially suited for forming small diameter, deep holes of any shape.

The electro-sparking process is characterized by relatively high electrode consumption. Local heating is not experienced under ideal operating conditions. The range of voltage usually employed is between 40 and 300 v. In a pure electro-sparking process the electro-discharge is initiated by the voltage across the dielectric. The process is electromechanical and not electrochemical (as the electrolytic process). The stock is removed by a sparking action and the metal or metal carbide particles are carried away suspended in the dielectric fluid.

Electro-Arcing Process—Cutting by the electro-arcing process is performed by making the work anode with an arc maintained between the work and the cathode. The method usually utilizes pulsating direct current using a moderately conducting electrolyte such as water glass solution. It is especially suitable for rapid cut-offs of hard metals and carbides and may be faster than existing cut-off procedures. However, in a pure electro-arcing process, somewhat rough finishes are obtained.

In the electro-arcing process, low voltages of less than 25 v are usually used. For electro-arcing process the electro-discharge is initiated by contacting the electrodes and current is carried by vaporized metal ions. The process is commonly characterized by the deposition of some nonconducting film (such as silica) on the work and high local heating is evidenced with moderate consumption of the cathode. As in the electro-sparking method, electro-arcing is essentially electromechanical in nature, in that the metal or metal carbide is not removed by an electrochemical reaction.

Ultrasonic Process—As differentiated from the electro-processes described above, the ultrasonic process does not utilize electric current directly for stock removal. Cutting or stock removal is accomplished by abrasive action at high frequency and low amplitude. Unlike the electro-process, the ultrasonic technique grinds nonmetals or nonelectrically conducting bodies as well as electrically conducting materials.

In the ultrasonic process, the cutting or grinding tool is usually vibrated in the frequency range from 16,000 to 29,000 cycles per sec through an amplitude of not more than a few thousandths of an inch. The abrasive, which is usually 280-grit boron carbide, is carried in water to the tool and work. Other grit sizes and abrasive compounds, such as aluminum oxide and silicon carbide, may be used but these do not last as long as boron carbide. Consumption of the tool occurs during grinding and machining.

Combination Processes—In addition to the four processes described above, machines may be devised for effecting combinations of some of these four processes. For example, the combination of the electrolytic and diamond wheel grinding has been tested and is being developed. For this combination process, a metal bonded diamond wheel must be used for the cathode. The diamond particles act as insulating spacers, separating the work from the wheel, and as scrapers.

Machines have been tested and are being designed for effecting machining and grinding by electrolytic and or electro-arcing actions. The same electrolyte or more than one electrolyte might be used by the same equipment which will serve for either the electro-arcing or the electrolytic process.

Electro-arcing, electro-sparking, and electrolytic actions might occur simultaneously during a grinding or cutting operation. Machines predominantly operate on the basis of one of the processes but there may be other process mechanisms superimposed. The superimposition of more than one mechanism or process in a cutting or grinding operation could markedly alter the results obtained.

The ultrasonic technique might be used in combination with one of the electro-processes such as the electrolytic one. However, this has not as yet been tested.

Potential Applications

To evaluate the applicability of new processes for machining and grinding, it is necessary to consider the pertinent or important job items or operations. Eight important machining and grinding type operations are given in Table I. They are listed in order of

current diamond bort consumption and account for approximately 74 pct of the diamond bort consumed in the United States. This tabulation indicates the estimated applicability of the new machining and grinding methods, including diamond wheel grinding. These applicability ratings are based on current knowledge of methods as being developed in this country and they may change as new developments progress.

Conclusions

Most of the new processes and the combinations thereof appear promising as methods for conserving diamond bort for shaping and finishing sintered carbides and for performing operations on other hard-to-machine materials for important military end use items. Performance and costs for these new processes are not as yet well established.

The electrolytic process appears very promising as a means for flat off-hand grinding as applied to sharpening of single point tools. Since this application is the largest single consumer of diamond bort, the rapid development of this process for sharpening of single point tools offers possibilities for substantial relief of diamond bort. However, there are tens of thousands of diamond wheel grinders used for sharpening single point tools, and it would be necessary to bring in or convert at least thousands of machines to show any appreciable effect. Additional experimental work must be completed before these machines are ready for mass production.

The second most prolific consumer of diamond bort is the grinding of single point tool chip breakers. The ultrasonic technique appears to be adaptable for this purpose. Additional experimental work is necessary to properly appraise the method.

The sharpening of milling cutters and broaches and the grinding of projectile cores account for a substantial consumption of diamond bort. The electrolytic, electro-sparking, ultrasonic processes, and combinations of them, look like possibilities for these applications; but experimental programs in these fields have yet to be started.

On the forming of cemented carbide turbine bucket attachments and machining and grinding of titanium compressor discs, no commercial methods have been established and it may be necessary to develop some of the new processes at a very rapid rate to meet the demands of possible increased production for the military. The electro-sparking and ultrasonic processes appear applicable for forming turbine bucket attachments and rifling of gun barrels; the electrolytic process appears promising for machining and grinding of compressor discs.

None of the new processes are in actual commercial use except for shaping and finishing dies. However, a limited number of machines, based on these new processes, are becoming available for practical test work. For producing tools such as single point tools, chip breakers, milling cutters and broaches, it will be necessary to carry the development work on these new processes through fairly extensive performance tests. These tests should not only be made on the machines but also on the tools themselves in order to adequately establish them as production units. At the same time research and development on machine improvements and on learning more fundamentals should proceed in a more intensified manner. The performance tests might best be done in production shops and eventually they must be done there. However, it may be worthwhile to design special programs for accelerated performance tests to exploit the methods as rapidly as possible. Performance tests and other research and development should be carried out mainly by industry who have the real need for these new processes.

Recommendations

Recognizing that several new processes for machining and grinding appear to offer promise both for saving diamond bort and for shaping materials urgently needed for our preparedness program, and that the rate of development effort should be accelerated to bring these methods into form suitable for large scale testing, it is recommended that:

1—The Army, Navy, and Air Force explore the application of these processes to relieve potential bottlenecks or shortages and allocate or seek funds in the furtherance of these objectives where government incentive is required. In the event that the military services are satisfied that the development of a particular technique is essential in the production of military weapons and equipment, the government will have a high incentive to participate in programs which will accelerate the development of these techniques. One of the fields which can be profitably and efficiently sponsored by government agencies is in the area of fundamental and basic research. Fundamental and basic programs will provide essential background information to industry for their machine development work after industry outlines the type of information which would be most helpful.

2—Industry should be encouraged to accelerate its efforts in research, and in machine developments, and in performance tests towards bringing these processes into industrial use as soon as possible. Government can assist industry in a number of ways: A—By making available needed equipment and supplies; B—by calling attention to urgently needed military end items which might require new machining and grinding processes; and C—by issuing contracts to industry for specific end item prototypes requiring the new processes.

3—An educational program should be undertaken. Tool users and others should be made aware of the critical diamond bort supply problem in relationship to their operations. The wasteful use of diamond bort should be discouraged. In addition, publicity should be given to the new promising processes which might in time relieve the diamond bort shortage. The educational program may take on a variety of forms and could be handled in part by a proper government agency, such as NPA, which is primarily concerned with the diamond bort supply problem. Others, such as editors of trade journals, technical societies, and specific industrial organizations, should be asked to participate in any educational program.

4—A committee should be set up to disseminate present and future pertinent information dealing with machining and grinding processes for use of governmental agencies. It appears important that there be some centralization of liaison and coordination so that the different government agencies can be properly informed and advised with a minimum of unnecessary duplication of effort. For example, the Office of Technical Information Service, Commerce Dept., or the Armed Services Technical Information Agency, Dept. of Defense, are in a position to undertake this assignment.

Isothermal Transformation Characteristics Of an Iron-Chromium Alloy of Titanium

by Charles W. Phillips and Donald N. Frey

A commercial Ti-Fe-Cr alloy, Ti-150, exhibits a martensitic transformation on cooling and two nucleation and growth reactions, one above and one below the M_s-M_f region, on isothermal holding below the single-phase β temperature range. The reactions were followed by metallographic, X-ray diffraction, and microhardness methods.

THE rapidly expanding engineering application of titanium and its alloys makes increasingly urgent an adequate knowledge of the effect of heat treatment on this material. The work herein reported is an attempt to determine certain aspects of the behavior of a commercially available alloy, Ti-150, during heat treatment.

The alloy, with a nominal composition of 2.7 pct Cr, 1.3 pct Fe, 0.25 pct O, 0.02 pct N, and 0.02 pct C, was received in the as-rolled condition as a $^3/_4$ in. round. Slugs 0.11 to 0.12 in. thick were cut under a coolant using a silicon carbide wheel. Preliminary work established that the alloy consists of two phases, α (hexagonal close-packed) and β (body-centered cubic), at temperatures below 1750° to 1775°F, and of only β phase at higher temperatures.

The slugs were heated for 1 hr in air at 1800°F to form a single-phase β matrix, then transferred to molten tin (1250° to 1650°F) or lead (1150°F and below) for isothermal holding. Holding temperatures ranged from 700° to 1650°F, times from 0.001 to 23 hr. The treated slugs were then sectioned, one part for metallographic examination and diamond pyramid hardness, the other, after deep etching to remove the high oxygen surface,[1] for comparative lattice parameter determination and X-ray phase identification.

Hardness measurements were taken on the lightly etched surfaces of the metallographic specimens; a 1000 g load on a 136° diamond pyramid was used. Five impressions on each sample were made and the average of the hardness calculated.

The use of microhardness measurements to follow the course of an isothermal transformation reaction is undesirable because of the possibility of wide differences in microconstituent hardness.[2] They were used in this case, however, because of the small amount of material available. At the higher transformation temperatures, where the above-mentioned objection was apparent, the readings were proportioned to correspond to the estimated ratio of transformed and untransformed constituents present.

Table I. Type I Reaction Temperatures and Times

Temperature, °F	Time of Start, Hr	Time of Finish, Hr
1650	0.01	1.0
1500	0.001-0.01	0.1-1.0
1450	0.001	0.1
1300	<0.001	<0.01

At lower temperatures, resulting in much finer microconstituents, the microhardness measurements were more uniform. The standard deviation of the mean of five impressions calculated from these latter values was 4.2 DPH. Employing 2σ limits (probability 0.95) the experimental error of the hardness measurements averages was 8.4 DPH.

The etchant used was composed of one part glycerol and one part 48 pct hydrofluoric acid.[1] Of a number of etches tried, this one appeared most satisfactory. All micrographs were taken at 500X magnification and with oblique lighting to permit easier identification of the acicular structure resulting from rapid cooling. No advantage was gained by using polarized light for metallographic examination.

Phase identification and lattice parameter measurements were made with a North American Philips high angle spectrometer in conjunction with a recording potentiometer. Considerable difficulty was encountered with some of the lattice parameter measurements because of the extreme broadness of the few diffraction lines obtained from samples consisting mainly of strained, untempered, quenched structures.

C. W. PHILLIPS, Member AIME, is Instructor, Dept. of Chemical and Metallurgical Engineering, University of Michigan, Ann Arbor, and D. N. FREY, Member AIME, formerly with the University of Michigan is now Member, Scientific Laboratory, Engineering Staff, Ford Motor Co., Detroit.

Discussion on this paper, TP 3258E, may be sent, 2 copies, to AIME by June 1, 1952. Manuscript, Sept. 7, 1951. New York Meeting, February 1952.

Fig. 1—0.001 hr at 1650°F. Acicular α formed on quenching from holding bath.

Fig. 2—0.01 hr at 1650°F. α formed by nucleation and growth in acicular α matrix.

Fig. 3—1.0 hr at 1650°F. Transformation complete.

Fig. 4—0.001 hr at 1300°F. α nucleated at grain boundary in matrix of acicular α.

Fig. 5—0.01 hr at 1300°F.

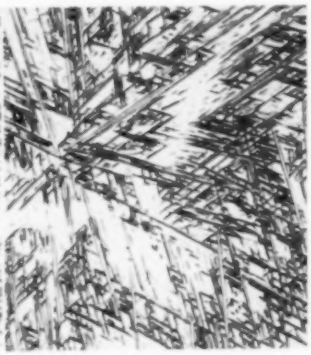


Fig. 6—14.5 hr at 1300°F.

Figs. 1-6—Micrographs of Ti 150 alloy after 1 hr at 1800°F, isothermally transformed. Etched in 50 pct glycerol, 50 pct HF. X500.

Only two lines of the high temperature β phase were persistent, the (110) at $\theta = 20°$ and the (220) at $\theta = 42°$. The α phase produced about six lines, all below $\theta = 44°$. None of the samples examined produced lines not attributable to either of the α or β patterns.

A wide variation in the β lattice parameter with treatment made comparative measurements possible utilizing the two lines mentioned. No corrections for absorption or eccentricity were employed, so the parameter values may be subject to considerable systematic error.

The method for lattice parameter measurement consisted of obtaining the angular difference between the lines, and using the relation:

$$\Delta\theta = \theta_{220} - \theta_{110} = \sin^{-1}\left[\frac{2.175}{a}\right] - \sin^{-1}\left[\frac{1.087}{a}\right] \quad [1]$$

derived from the Bragg equation.[7] Application of the same method for changes in the c axis of the α phase using the (002) and (004) lines was unsuccessful because the parameter variation is of the same order of magnitude as the experimental error, approximately 0.005A.

Results and Discussion

The $\alpha \rightleftarrows \beta$ transformation in pure titanium occurs at 1625°F. Addition of oxygen and nitrogen to titanium raises the transformation temperature[2] and explains the presently observed high value of 1750° to 1775°F for the upper limit of the two-phase field.

$$n\lambda = 2d \sin\theta$$

$$\theta = \sin^{-1}\frac{n\lambda}{2d}, \text{ incorporating } n \text{ into the expression for } d:$$

$$\Delta\theta = \theta_{220} - \theta_{110} = \sin^{-1}\left[\frac{\lambda}{2d_{220}}\right] - \sin^{-1}\left[\frac{\lambda}{2d_{110}}\right]$$

where $d = \frac{a_o}{\sqrt{(h^2 + k^2 + l^2)}}$

and $d_{220} = \frac{a_o}{2\sqrt{2}}$ $\quad d_{110} = \frac{a_o}{\sqrt{2}}$

Substituting for $\lambda = 1.538$ (unresolved CuK_{α}) and for d_{220}, d_{110}:

$$\Delta\theta = \sin^{-1}\left[\frac{2.175}{a_o}\right] - \sin^{-1}\left[\frac{1.087}{a_o}\right]$$

A plot of $\Delta\theta$ vs. a_o from this equation facilitated the parameter determination.

Fig. 7—0.01 hr at 1150°F. Acicular α formed on quenching to 1150°F.

Fig. 8—1.0 hr at 1150°F.

Fig. 9—16.1 hr at 1150°F. Tempered acicular α.

Fig. 10—0.01 hr at 1000°F. Acicular α formed on quenching to 1000°F.

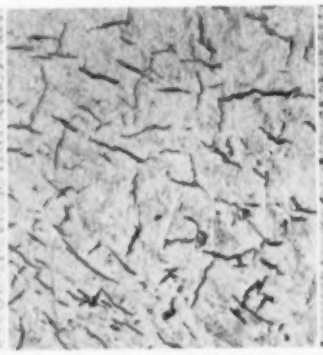


Fig. 11—1.0 hr at 1000°F. Unknown constituent in matrix of tempered acicular α.

Fig. 12—14.5 hr at 1000°F.

Figs. 7-12—Micrographs of Ti-150 alloy after 1 hr at 1800°F, isothermally transformed. Etched in 50 pct glycerol, 50 pct HF. X500.

Fig. 13—1.0 hr at 850°F.

Fig. 14—16.1 hr at 850°F.

Fig. 15—23.0 hr at 700°F.

Figs. 13-15—Micrographs of Ti-150 alloy after 1 hr at 1800°F, isothermally transformed. Etched in 50 pct glycerol, 50 pct HF. X500.

There are no published data on the phase relationships of the system containing the alloy under investigation, or neglecting oxygen, nitrogen, and carbon, any on the Ti-Cr-Fe system. The available information on the titanium-rich portions of the binary Ti-Fe and Ti-Cr systems,[7,8] however, indicates that a ternary eutectoid might reasonably be expected at some temperature below 1100°F. No microscopic or X-ray evidence of the presence of this reaction was obtained.

Three basic types of reactions are observed over the temperature range of isothermal holding investigated, and hereafter will be referred to as types I, II, and III.

Type I, extending from the single-phase β temperature to about 1250°F, is a typical nucleation and

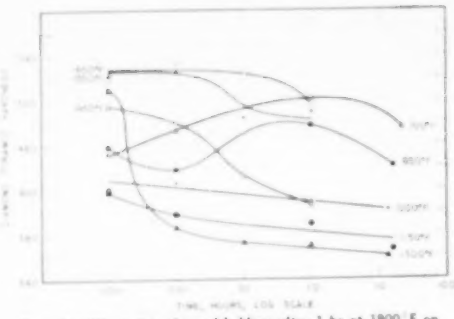


Fig. 16—Effect of isothermal holding after 1 hr at 1800°F on the diamond pyramid hardness of Ti-150.

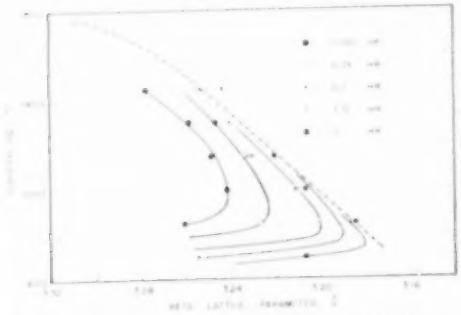


Fig. 17—Effect of isothermal holding after 1 hr at 1800°F on the lattice parameter of the β phase of Ti-150.

growth reaction (Figs. 1 to 6). Above 1550°F, nucleation occurs generally throughout the β matrix; at 1550°F and below, nucleation occurs mainly in the grain boundaries. The structure of the reaction product, α, becomes finer and more linear with decreasing temperature of transformation (compare Figs. 3 and 6). On quenching from the holding bath untransformed β is converted to an acicular product.

Although insufficient work was done to establish accurately the start and finish times of this reaction, estimates of these quantities are presented in Table I. This reaction is one of nucleation and growth of α from a supersaturated β matrix, as revealed by X-ray phase identification.

Type II reaction is represented by Figs. 7 to 9. No isothermally formed product is evident. The acicular structure formed on cooling to the transformation temperature undergoes a gradual coarsening with increasing delineation of the individual plates. The temperature range extends from about 1150°F to about 1000°F. This is interpreted to be the formation of acicular α (also called α') upon quenching to the holding bath temperature, followed by tempering (release of transformation strains) plus approach to equilibrium phase compositions by diffusion.

Table II. Type III Reaction Temperatures and Times

Temperature, °F	Time of Start, Hr
1000	0.01-0.1
850	0.1-1.0
700	1-20

The X-ray diffraction patterns obtained from martensitic samples, although consisting of broad lines, were apparently only from highly strained α, and not a transition structure.

Type III reaction commences somewhat above 1000°F and is shown in Figs. 10 to 15 as the formation of dark-etching, irregular plates which increase in number and decrease in size with decreasing temperatures.

Table II presents the time-of-start estimates for the reaction. Completion times were too uncertain to be significant. This reaction is believed to be either the transformation of small islands of retained β into α or the formation of β from acicular α, the latter formed by the martensite reaction on quenching.

The results of the hardness measurements are shown in Fig. 16. Those series within the Type I transformation temperature range (above 1250°F) decrease in hardness from a high initial value at rates which are inverse functions of the temperature. Intermediate temperatures (1000° to 1150°F) corresponding to the Type II reaction also show a hardness decrease with time, but have much lower initial values. The low temperature series show an increase in hardness with time, to a maximum, characteristic of the effect of precipitation from solid solution.

The hardness results are explained on the basis of the three types of reactions noted. Down to 1300°F, short-time holding allows relatively little transformation, so the β matrix is transformed to martensite on quenching, yielding a hard product. The rate of hardness drop is directly related to the

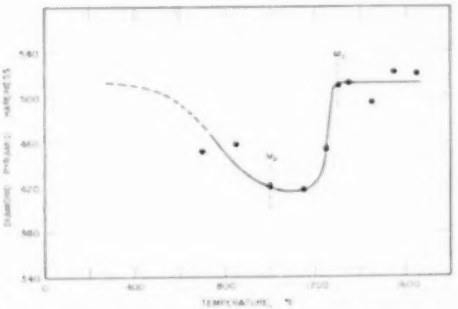


Fig. 18—Determination of the M_s-M_f region of Ti-150 on the basis of diamond pyramid hardness of samples transformed 0.001 hr at various temperatures after 1 hr at 1800°F.

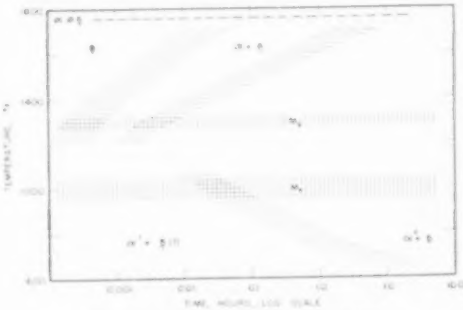


Fig. 19—Tentative TTT diagram for Ti-150.

starting time and velocity of the Type I reaction. The final hardness after completion depends on the equilibrium amounts of α and β, and upon the β composition, which, with higher alloy content, does not transform to martensite but is retained on quenching.

The comparative softness of the first samples of the intermediate temperature series is due to the rapid relief of strain of the martensite matrix formed during cooling. Further hardness decrease in the Type II reaction is due to gradual coarsening of the α-β plate structure. As the holding temperature is lowered, the 0.001 hr hardness increases because of the decreasing tendency to relieve strain.

The effect of time and temperature on the β phase lattice parameter is shown in Fig. 17. The dashed line corresponds to the boundary separating the $\alpha+\beta$ and the single-phase β fields, as determined by the minimum β lattice parameter (maximum alloy content, since Fe and Cr contract the Ti lattice) at a given temperature. With the exception of the short holding times at 700°F, measurable β lines were obtained from all treatments. The lattice parameters approach their equilibrium values at decreasing rates with decreasing temperatures. There are no obvious discontinuities in the parameter changes corresponding to the three types of microstructural changes cited.

The absence of a δ phase in the 1000° to 700°F transformed samples indicates that either the ternary eutectoid temperature has not been reached, or, more likely, from the evidence of the binary Ti-Fe and Ti-Cr systems,[5,6] the transformation to a low temperature δ phase is very sluggish.

The dark-etching constituent formed at 1000°F and below appears after the maxima in the precipitation hardening curves are passed, indicating that it is evidence of overaging. High magnification examination did not reveal a discernible fine structure within the particles, but it is thought that the dark appearance is caused by staining of a fine dispersion of β in an α matrix.

Determination of the M_s and M_f temperatures of the martensitic transformation is from the hardness data at 0.001 hr holding time, Fig. 18. It is reasonable to assume that an appreciable amount of martensite must be formed during cooling to the holding temperature in order that the total hardness may be lowered noticeably. Thus the M_s may be placed at approximately 1300°F. The M_f, indicated by cessation of the hardness drop, is considerably more uncertain, in the neighborhood of 1000°F. These conclusions may be represented graphically on a conventional TTT diagram, Fig. 19.

Conclusions

1—The titanium-rich Ti-Fe-Cr alloy, Ti-150, exhibits a martensitic reaction on rapid cooling from the single-phase body-centered cubic β region to form a supersaturated hexagonal close-packed α. The M_s-M_f region is approximately 1300° to 1000°F.

2—Between 1750° and 1250°F, β decomposes isothermally to α and β of equilibrium composition by nucleation and growth; nucleation occurs throughout the β matrix above 1550°F, and only at the grain boundaries below 1550°F.

3—At 1000°F and below, a precipitation reaction occurs causing an increase in hardness to a maximum, and eventually the growth of a dark-etching constituent as yet unidentified.

Acknowledgment

The authors wish to express their appreciation to the Allegheny Ludlum Steel Corp. for furnishing the material used in this investigation.

References

[1] E. A. Anderson: Symposium on Metallography of Titanium. Sponsored by the Armour Research Foundation, Illinois Institute of Technology, June 13, 1951, Chicago.

[2] R. Haynes: *Trans.* AIME (1951) **191**, p. 554; JOURNAL OF METALS (July 1951). Discussion of paper by R. H. Fillnow and D. J. Mack: *Trans.* AIME (1950) **188**, p. 1229; JOURNAL OF METALS (October 1950).

[3] W. L. Finlay, J. Risketo, M. B. Vordahl: *Industrial and Engineering Chemistry* (1950) **42**, p. 218.

[4] R. I. Jaffee, H. R. Ogden, D. J. Maykuth: *Trans.* AIME (1950) **188**, p. 1261; JOURNAL OF METALS (October 1950).

[5] H. W. Worner: *Journal* Inst. Metals (1951) **79**, 3, p. 173.

[6] M. K. McQuillan: *Journal* Inst. Metals (1951) **75**, 5, p. 379.

Technical Note

Use of Etch Figures for Micrographic Investigations of Commercially Pure Aluminum and Aluminum Alloys

by Jean Herenguel

THE published work of Lacombe and Beaujard[1] has demonstrated the interesting application of etch figures to the determination of crystal orientations in aluminum by a purely micrographic method.

J. HERENGUEL is Director of the Department of Research, Trefileries et Laminoirs du Havre, Antony, Seine, France.

TN 100E. Manuscript, Aug. 20, 1951.

The geometry of these figures leaves no ambiguity and the method has the added advantage of being applicable to very small crystal units. These authors applied the technique to the study of high purity aluminum, and it has now been adopted by Herenguel and his collaborators to various researches on commercial aluminum, containing up to 1 pct Fe and Si. This must modify the opinion pointed out by

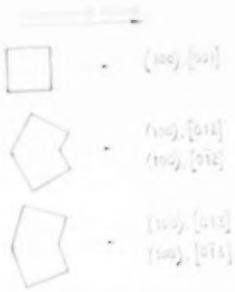


Fig. 1—Orientation relationships in a complex cubic texture. Aluminum of 99.5 pct purity, rolled and annealed.

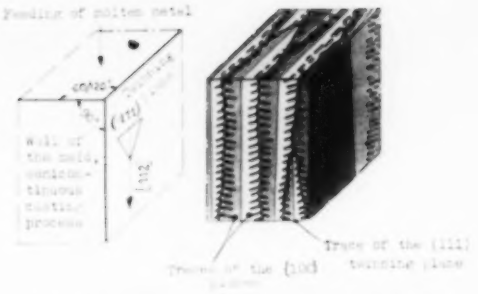


Fig. 3—Solidification texture with twinned leaves in semicontinuous castings of aluminum of 99.5 pct purity.

Servi and Grant in their recent work.[1] For preferential orientation textures, the individual orientation of each grain has been determined and various relationships have been interpreted quantitatively.

Thus without any ambiguity, orientations in a whole polycrystalline aggregate can be defined precisely, while additional evidence (from slip band traces after light plastic deformation, from thin oxide films yielding interference tints of different color, and from examination of thicker oxide films in polarized light) confirms completely the results of this analysis.

J. Herenguel and F. Santini[2] have in this way analyzed a recrystallization texture in aluminum (purity, 99.5 pct) after the rolling of an ingot from a semicontinuous casting process. The following relations, shown in Fig. 1, have been identified.

With the same etching, it was also possible to distinguish the macrographic pattern of the cubic texture. Fig. 2 shows this appearance at a low magnification. The dark areas are covered by triangular figures in great numbers, while the light regions carry a few square figures, revealing areas of cubic texture. (On Fig. 2, the etch figures are too small to be seen on this macrographic scale.)

Etch figures have also been used by Herenguel to analyze a type of solidification texture encountered frequently in semicontinuous castings of aluminum of commercial purity. This relationship, which until now has passed unnoticed, is of striking regularity; sometimes nearly the whole ingot is formed of flat crystals, each of these being itself made up of two half-twins (see Fig. 3). Each twin is oriented in essentially the same way. The (111) plane, common to the two parts of the twin, is both in a vertical position and nearly perpendicular to the wall of the mold, the [112] axis of each double leaf is vertical. In addition, segregation of the constituents (Al, Fe, Si) occurs at the boundaries of the leaves (which are almost completely filled) and also on the {100} planes on either side of each twin. By contrast, the twin boundaries, and their immediate neighborhood, are free of any constituent. The analyses of this arrangement has been confirmed by X-ray studies[3] but with much difficulty; while etch figures have permitted an easy and complete analysis and a definite identification.

Finally, etch figures can also give some indication of local composition differences in the solid solution.[4] Applied to solidification textures in commercial aluminum alloys, they have enabled us to show that the separation of phases on the {100} planes is quite general. Around such phases, the composition of the solid solution undergoes considerable variation (enrichment or impoverishment). As the number of etch figures is related to the composition (as in all engraving etches) the homogeneity or variations of composition of the solid solution can be studied, with reference to the metallurgical treatments. All these studies have been carried out using the classical reagent of Lacombe, the only precaution residing in the precise definition of polishing conditions preceding the attack. It must be noted that with metal of commercial purity, the etch figures are sometimes truncated; however, by observing the cube edges of the etch-pit or, rather, their projection on the surface, it is easy to determine the exact shape of the basic figures and to measure the angles exactly.

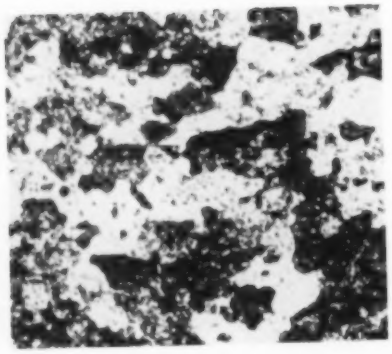


Fig. 2—Aluminum of 99.5 pct purity, rolled and annealed, electrolytically polished and etched in Lacombe's reagent. Cubic texture, see Fig. 1. X100.

References

[1] P. Lacombe and L. Beaujard: *Journal* Inst. Metals (1947) **74**, p. 1.

[2] I. S. Servi and N. J. Grant: *Trans.* AIME (1951) **191**, p. 473; JOURNAL OF METALS (June 1951).

[3] J. Herenguel and F. Santini: *Metaux et Corrosion* (1946) XXI, 254, p. 131.

[4] J. Herenguel: *Revue de Metallurgie* (1948) XLV, 12, p. 505.

[5] J. Herenguel and P. Lacombe: *Comptes Rendus* Acad. Sciences (1949) 228, 846.

[6] J. Herenguel: *Revue de Metallurgie* (1950) XLVI, 1, p. 29.

Sintered Titanium Carbide

by Frank W. Glaser and W. Ivanick

A pressure-sintering method was used to produce binder-free and very dense TiC specimens. Some physical properties of these TiC bodies were determined and found to compare favorably with those of certain cemented TiC grades. It was also observed that the hot transverse rupture strength of TiC bodies remained substantially the same regardless of the amount or type of binder material used.

STUDIES of the structure and physical properties of refractory materials have been intensified recently because of the urgent need for nonstrategic materials that retain their strength at high temperatures. Research aimed at determining and improving the physical properties of cemented carbides and borides has been accelerated with a view toward possible use of such materials in connection with turbine blades, rocket nozzles, and other high temperature applications.

On the hypothesis that the strength requirements in connection with some of the above applications could be met only by proper choice of cementing agents for such refractory materials, the literature describing the physical properties of borides or carbides was reviewed. However, with a few exceptions,[1] references were found only to compositions containing at least one or more auxiliary binder metals. Cobalt and nickel are among the most frequently employed cementing agents.

The melting point of TiC (approximately 3250°C) and therefore the sintering temperature, at which notable densification of a cold pressed TiC powder compact could be expected in the absence of a liquid binder phase, is relatively high. The present study makes use of a high temperature, pressure-sintering procedure, recently described by one of the authors in connection with the sintering of binder-free ZrB_2,[2] to produce dense bodies of sintered TiC—free of any cementing agent. During the course of this sintering study, some physical properties of dense TiC bodies produced by this method will be discussed.

F. W. GLASER, Junior Member AIME, and W. IVANICK are associated with American Electro Metal Corp., Yonkers, N. Y.

Discussion on this paper, TP 3288E, may be sent, 2 copies, to AIME by June 1, 1952. Manuscript, April 13, 1951; revised, Sept. 26, 1951. Detroit Meeting, October 1951.

Table I. Chemical Composition of TiC Grades Employed

	Ti, Pct	Combined C, Wt Pct	Graphitic C	
			Wt Pct	Atomic Pct
Grade 1	79.5	18.4	1.3	3.4
Grade 2	79.1	19.3	0.6	1.5
Theoretical Composition	79.3	20.7		

Materials, Preparation of Samples, Testing Methods

The procedure for the forming of TiC powder consisted of mixing graphite and TiH_2 powders in stoichiometric proportions, and heating this mixture in a H_2 atmosphere and carbon crucible by high frequency, to temperatures ranging between 1900° and 2100°C (3452° and 3812°F). The powdered carbide was then comminuted and screened to the desired particle size. Table I shows the chemical analysis of the two grades that were employed for the production of samples during this work. Bodies of TiC, approximately 2.5x1x0.5 cm were produced in graphite molds that were heated by direct conduction. Sintering was carried out at temperatures for time intervals ranging from approximately 0 to 30 sec under a constant pressure of about 1.3 tons per sq in.

An alternate method for the production of samples consisted in cold pressing the individual TiC grades at pressures ranging from 4 to 10 tons per sq in. and sintering in a hydrogen atmosphere in graphite crucibles heated by high frequency induction. Sintering temperatures ranged from 2600° to 2900°C (4715° to 5255°F). Electrical testing was done by measuring potentiometrically the voltage drop over a length of 1.5 cm for a current of 10 amp at room temperature. Cross-sectional areas as well as densi-

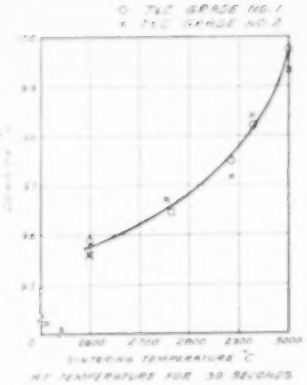


Fig. 1—Density vs. sintering temperature relationship

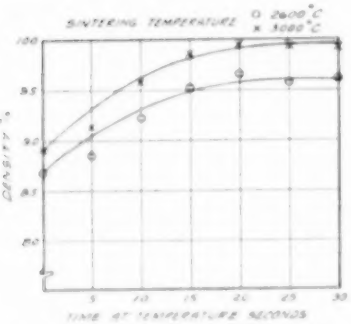


Fig. 2—Effect of time at temperature on densification of TiC compacts

ties of the samples under test were determined by the immersion method.

To determine transverse rupture strength, specimens were broken over a 9/16 in. span, at room temperature. X-ray diffraction examination of TiC powders was carried out with a Norelco Recording Spectrometer.

To evaluate specimen densities in terms of their X-ray density, the parameter of the face-centered cubic metal lattice of grade No. 2 was determined and found to be $a_o = 4.3221$A. The calculated X-ray density is therefore $D = 4.93$ g per cc. Correcting the value of 4.93 g per cc for 1.3 and 0.6 wt pct of graphitic carbon, densities of 4.85 and 4.89 g per cc, respectively, were calculated to be the theoretical densities of the TiC grades employed for the production of samples during the course of this work. Unless otherwise stated, all particle sizes of TiC grade 1 or grade 2 powders were through 325 mesh (44 microns average particle size).

Results

Control of degree of completion of the sintering process is usually obtained with density or electrical resistivity measurements. Of these two, density determinations are believed to be a more direct method because of their relative insensitivity to small amounts of impurities as compared with electrical measurements. The effects of sintering temperature and time on the density are shown in Figs. 1 and 2.

Fig. 1 shows the relationship of the density vs. sintering temperature for the two TiC grades employed. Samples had been kept at temperature and under pressure for 30 sec. This time period of 30 sec represents the time at temperature required to obtain optimum density values, and time periods in excess of 30 sec did not produce any measurable increases in density. It can be seen here that a very strong temperature dependency of the density still exists in even the very high density regions (98 pct and higher). No appreciable difference in densification for the different carbide grades could be observed. Fig. 2 describes the influence of time at temperature on the density of TiC (grade 2) compacts. Temperature is the parameter for the curves plotted in this figure. An optimum value of 99.4 pct of the theoretical density could be obtained for a TiC specimen of grade 2, if kept at 3000°C (5435°F) for 30 sec under continuous pressure.

In Figs. 3 and 4, the electrical resistivity and transverse rupture strengths of the two TiC grades are plotted as a function of the density. Since the density was shown (Figs. 1 and 2) to reflect both the influence of temperature as well as that of time at a given temperature, physical properties were plotted against density and extrapolated to 100 pct in order to obtain material properties for the two grades of TiC powders of through 325 mesh particle size. The electrical resistivity of TiC was thereby determined to be approximately 72 microhm-cm, while the transverse rupture strength ranged between 85,000 to 95,000 psi.

From the data reported in Figs. 1 through 4, it is apparent that optimum values for pressure-sintered TiC could be obtained for grade No. 2 if processed at approximately 3000°C for 30 sec. These conditions were therefore chosen to produce compacts of grade No. 2 TiC and to study the influence of particle size on density, electrical resistivity, and transverse rupture strength. The properties reported in Table II were obtained on specimens (grade No. 2) that were heated to 3000°C under continuous pressure and kept at this temperature for about 30 sec. The data of this table show that densification, electrical conductivity, and transverse rupture strength are improved considerably by the use of smaller average particle size powders. Average particle sizes of 8 and 2 microns were estimated microscopically.

As demonstrated by the data of Table II, particle size effects are evidently strongest with regard to the transverse rupture strength. It was possible to obtain values in excess of 120,000 psi by the use of a powder having an average particle size of approximately 2 microns. However, it proved rather diffi-

Table II. Influence of Particle Size on the Properties of Sintered TiC*

Average Particle Size, Microns	Density, Pct	Electrical Resistivity, Microhm-cm	Transverse Rupture Strength, Psi	Hardness, Rockwell A
74 to −44	98.6	78.3	73,500	88.5–89
44 to −37	99.3	72.0	91,000	89.5–89
37 to −8	100	72.1	100,000	91.5–92
8 to −2	100	68.2	124,000	92.5–93.5

* All data reported are the averages of at least two measurements.

cult to further reduce particle sizes of the powders employed here and still maintain purity. Electrical resistivity values of 105, 193, and 70 microhm-cm respectively have been reported,[1] while during the course of this work a value of 68 microhm-cm was determined for very dense TiC compacts. The temperature coefficient of the electrical resistivity was found to be 0.0032 at 22°C. The thermal conductivity of such samples was measured to be 0.110 watts per cm per °C between 20° and 100°C. The product of electrical resistivity and thermal conductivity is therefore equal to 7.48, a value that nearly corresponds to the normal Wiedemann-Frantz ratio of 7.5.

Corrosion tests in air at 1000° and 1150°C revealed that the oxidation resistance of dense and binder-free TiC bodies is relatively poor, if compared, for instance, with such very corrosion resistant materials as zirconium-boride or molybdenum-disilicide. It is, however, superior in corrosion resistance to certain nickel and cobalt cemented titanium carbide grades. Some comparative data are shown in Table III.

Transverse rupture strength values as determined by other investigators[2] for cemented TiC bodies are compared with the strength values obtained on straight TiC bodies during the course of this work in Figs. 5 and 6.

Discussion of Results

Figs. 1 and 2 demonstrate the importance of very high sintering temperatures and times at temperature (under pressure) to obtain maximum densities. Approximately 30 sec at 3000°C were needed in order to obtain a specimen approaching 100 pct density and exhibiting a relatively high transverse rupture strength. While the electrical resistivity remains fairly constant over the 95 to 100 pct density region (Fig. 3), the effect of reduction in pore space upon the transverse rupture strength over this same density range is great (Fig. 4). The strength of TiC bodies is reduced by a factor of two by as little as 5 pct of voids. Chemical analysis of the powder, as well as particle size, also influenced to a considerable extent the mechanical properties of TiC bodies produced during this investigation; nevertheless to obtain the strongest TiC specimens, the emphasis had to be on the sintering techniques employed. The production of these high density TiC materials permitted a good evaluation of some physical properties of this compound, which, on the basis of electrical measurements at least, exhibits very definite metallic behavior.

Having demonstrated that high transverse rupture strength bodies may be produced from titanium carbide powders of high purity and by the use of very high sintering temperatures at sintering pressures higher than atmospheric pressure, a comparison of the transverse rupture strengths of binder-free titanium-carbide bodies with that of "cemented" titanium carbides, as carried out in Figs. 5 and 6, becomes extremely interesting. Considering the curve in Fig. 5, it appears that the additions of 5 or 10 pct binder to TiC have very little, if any, effect on its transverse rupture strength. A higher transverse rupture strength and a maximum value are obtained, however, with approximately 20 pct binder additions.* It is conceivable that, by the use of still purer powder grades and finer particle sizes, the mechanical strength of binder-free bodies could be further increased and could possibly approach, if not exceed, the maximum transverse rupture strength as shown in Fig. 5. During the hot transverse rupture strength testing of TiC (cemented as well as binder-free compositions), it was found that all TiC materials, regardless of the amount or nature of the binder present, behaved very much alike. The curve of Fig. 6 shows what has been frequently referred to as the "gradual softening" of the binder

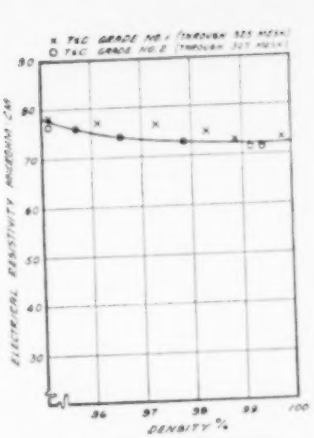


Fig. 3—Influence of density increases on the electrical resistivity of TiC compacts.

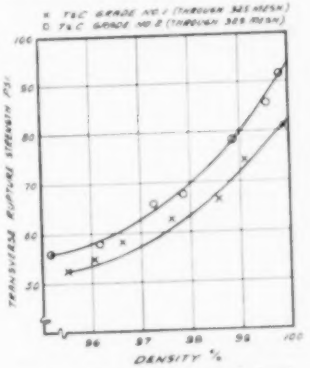


Fig. 4—Influence of density on the transverse rupture strength of TiC compacts. Numerical values of the ordinate times 1000.

Table III. Comparison of Air Corrosion Resistance at 1150°C of Dense and Binder-Free TiC Bodies with Other Materials*

Material	Weight Gain in Mg per Sq Cm After:					
	8 Hr	16 Hr	24 Hr	32 Hr	48 Hr	200 Hr
TiC Grade 1	6	7	7	9	Failed†	
TiC Grade 2	4	5	5	6	Failed	
TiC, 10 pct Co	10	18	Failed	Failed	Failed	
TiC, 20 pct Co	8	12	Failed	Failed	Failed	
TiC, 10 pct Ni	5	9	18	Failed	Failed	
$MoSi_2$	2	4	5	5	6	8
ZrB_2	0.5	1.2	2	3	3	4

* All data reported here were compiled by this laboratory.
† Failed on basis of weight gain in excess of 20 mg per sq cm.

* This value, as well as the solid solution values reported in Fig. 6 were taken from an article published by Redmond and Smith.[2] This laboratory was unable to reproduce the high transverse rupture value obtained by these authors for the 80:20 TiC-Co composition.

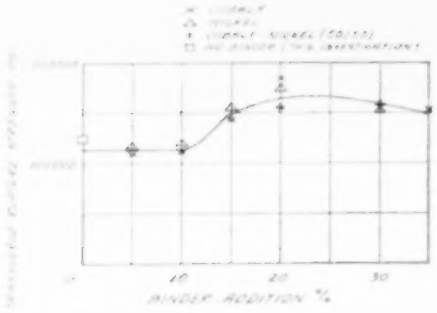


Fig. 5 (above)—Effect of binder additions on the transverse rupture strength of TiC compacts.

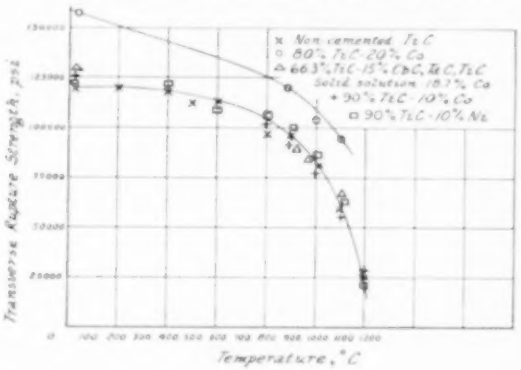

x Non cemented TiC
○ 80% TiC-20% Co
△ 66⅔% TiC-15% (TiC, TaC, TiC Solid solution)-18⅓% Co
+ 90% TiC-10% Co
□ 90% TiC-10% Ni
Transverse Rupture Strength, psi
Temperature, °C

Fig. 6 (right)—Transverse rupture strength of various titanium carbide grades as a function of temperature.

phase. The transverse rupture strength of materials reported in Fig. 6 dips to near zero strength at about 1200°C.

The fact that the binder-free titanium carbide also follows this pattern of "gradual softening" induces the thought that either an impurity acting as a binder, a low melting titanium carbide-carbon eutectic, or a weakening of the titanium carbide structure as such, could be responsible for the reduced strength exhibited by binder-free TiC samples at relatively low temperatures. This latter thought would be of course in contradiction to empirical rules relating the strength of materials to their melting points. Very little is known about the existence of a carbon-titanium carbide eutectic. With regard to impurities present, this material was analyzed spectroscopically and some wolfram (X) and cobalt (0X) were found. A microscopic examination disclosed the presence of a very small amount of impurities believed to be oxides.

The current question of whether the binder phase is responsible for the high strength of an aggregate of carbide grains, or whether the binder phase serves the purpose of repairing microcracks or flaws within a continuous carbide skeleton can certainly not be answered by the data of this work. However, for the specific case of titanium carbide bodies, some valuable conclusions can be drawn on the basis of some of the results obtained during the course of this investigation.

The effect of the removal of the last 5 pct of pore space on the strength characteristics of compacts was demonstrated in Fig. 4. If now the carbide phase of a bonded TiC body should consist of a continuous skeleton, the binder phase, in improving the strength of a porous carbide compact, has probably filled its voids, rather than "cemented" individual carbide particles, as is very often assumed to be the case.

In view of the data reported in Fig. 6, there seems to be but little doubt about an important contribution to the transverse rupture strength of the carbide body itself, since the hot strength of titanium carbide bodies remained unaffected by the amount or type of binder material employed. Since the transverse rupture testing method is rather sensitive to mechanical defects of a body, it would be conceivable that the strength of such a carbide compact might be governed by the amount of mechanical imperfections, with binders acting as the crack healing substance. Therefore, better processing conditions might increase strength values of titanium carbide bodies through crack elimination with improved sintering methods, rather than binder additions.

Summary

It has been shown that the pressure-sintering method permits the production of very dense, binder-free TiC bodies, exhibiting physical properties that are generally superior to data previously reported in the literature. Two grades of TiC, containing varying amounts of graphitic carbon, were prepared and the physical properties of these two grades were related to chemical composition, powder particle size, sintering times, and temperatures. The transverse rupture strength of pressure-sintered, binder-free TiC bodies compares favorably with that of cemented carbides containing up to about 10 pct binder. The hot strength of titanium carbide bodies appears to be unaffected by the amount or type of binder material employed.

Acknowledgment

A portion of this work was carried out under contract with the Office of Naval Research. The authors wish to thank the agency for permission to publish these data.

References

[1] P. Ehrlich: *Ztsch. anorg. allgem. Chem.* (1949) **259**.
[2] F. W. Glaser: *Powder Metallurgy Bull.* (1951) **6**, p. 1.
[3] R. Kieffer and F. Koelbl: *Powder Metallurgy Bull.* (1949) **4**, p. 1.
[4] E. Ryschkewitsch: Properties and Physical Constants Data. U. S. Air Force, Wright-Patterson Air Force Base, Dayton, Ohio.
[5] R. Kieffer: Private communication.
[6] J. C. Redmond and E. N. Smith: *Trans.* AIME (1949) **185**, p. 987; JOURNAL OF METALS (December 1949).

Contribution to the Metal-Carbon-Boron Systems

by Frank W. Glaser

Metal-carbon-boron powder mixtures were hot pressed and the resulting specimens were studied by X-ray diffraction. It was found that regardless of the starting combination of the metal, carbon, or boron powders, a metal boride phase was always the major component in these samples. In the absence of carbon the boride phase formed on hot pressing depended only on the amount of boron present. Two new phases of the system Ti-B were found. They are Ti_3B and TiB_{12}. The existence of a controversial face-centered cubic phase of formula TiB was confirmed. Electrical resistivities were measured for various boride phases. It was found that the diborides are generally better conductors than the monoborides of the same metal.

THE carbides and borides of the transition elements have very high melting points, in the range 2500° to 4000°C, and are therefore of interest as high temperature materials. The literature on the stability or chemical reactivity of these carbides and borides is very scarce. Various investigators[1-3] have demonstrated a relative instability of certain carbide phases in the presence of boron or boron-containing substances.

In a recent publication, Glaser[1] demonstrated the stability of zirconium-boride (ZrB_2) in the presence of carbon at temperatures in excess of approximately 2900°C, while during a preliminary investigation of boride phases, Steinitz[2] concluded that the diborides are stable in the presence of carbon while the monoborides of the fourth and fifth group are not, forming diborides plus carbides instead. Nelson, Willmore, and Womeldorph[3] have elaborated on the reaction $B_4C + 2TiC = 2TiB_2 + 3C$, which was known to occur because of a relative instability of B_4C and the great tendency towards TiB_2 formation at relatively low temperatures (approximately 1200°C). A similar study, involving as starting materials TiO_2 and B_4C and resulting in TiB_2, was recently described by Honak[4], who observed the beginning of an exothermic reaction of a TiO_2-B_4C powder mixture, which, when preheated in a hydrogen atmosphere to approximately 950°C, was carried to about 1600°C by the heat of reaction.

To shed more light on reactions of this type (Metal-C-B), the final product apparently always resulting in a boride phase at the expense of a carbide phase,* a systematic investigation was started and the following is an account of some of the results that were obtained.

* Boride phases of various metals, as reported to date, are listed in Table I.

Materials, Preparation of Samples, Testing Methods

The raw materials employed for this work consisted of various carbide, boride, and metal powders, as well as of boron and graphite powders. In cases where commercial grades of carbides were considered unsuitable because of low purity or excessive amounts of graphitic carbon, such carbide powders were prepared by this laboratory. The procedure for the preparation of carbide powders (zirconium carbide, titanium carbide, tantalum carbide, and niobium carbide) consisted of mixing graphite and the respective metal hydride powders in stoichiometric proportions and subsequent heating of such mixtures in a hydrogen atmosphere in carbon crucibles. The heating was by high frequency to temperatures ranging between 1700° and 2100°C. The resulting carbide was then comminuted and screened to the desired particle size.

ZrB_2 and TiB_2 powders were produced by the electrolysis of fused salt baths, according to the method described by Andrieux.[5] The borides of niobium, vanadium, tantalum, molybdenum, chromium, and iron were obtained by mixing the respective metal and boron powders in the desired proportions. Such metal-boron mixtures were heated in a high frequency furnace to form boride powders.

For each metal-carbon-boron group (Tables II through XI) a metal, its hydride, carbide or boride were mixed with carbon, boron or boron carbide powders. The additions of carbon, boron or boron carbide powders to any of these metals or metal compounds were calculated to satisfy a particular carbide or boride phase that according to the literature (Table I) had definitely been established by X-ray diffraction work. Samples of powder mixtures were hot pressed in graphite molds that were heated by direct conduction. The specimen dimensions were approximately 2.5x1x1 cm. Hot pressing temperatures were measured optically and maintained for approximately 30 sec under a constant pressure of about 1.3 ton per sq in. Wherever possible, an attempt to obtain maximum specimen density was made by temperature variation.

Electrical resistivity testing was done by measuring potentiometrically the voltage drop over a length of 1.5 cm for a current of 10 amp, at room temperature. To obtain electrical resistivities for specific carbide or boride phases, values were plotted as a function of the respective sample densities

F. W. GLASER, Junior Member AIME, is associated with the American Electro Metal Corp., Yonkers, N. Y.

Discussion on this paper, TP 3281E, may be sent, 2 copies, to AIME by June 1, 1952. Manuscript, Aug. 1, 1951; revised, Jan. 22, 1952. New York Meeting, February 1952.

Table I. Phases of Some Boron Metal Systems As Reported to Date

Metal	Boride Phases Reported
Zr	ZrB_{12}, ZrB_2, Zr_3B_4, ZrB[a]
Ti	TiB_2, TiB, Ti_3B_4,[a] Ti_2B[a]
V	VB_2,[a] VB[a]
Ta	TaB_2, Ta_3B_4, TaB, Ta_2B, Ta_3B_2[a]
Nb	NbB_2, Nb_3B_4, NbB, Nb_2B, Nb_3B_2[a]
W	WB_4, WB, W_2B_5, beta-WB[a]
Mo	MoB_2, Mo_2B_5, MoB, Mo_2B,[a] beta-MoB,[a] Mo_3B_2[a]
Cr	CrB_4, Cr_3B_4, Cr_5B_3, CrB, CrB_2[a]
Fe	FeB, Fe_2B[a]
Th	ThB_4, ThB_6[a]

and the extrapolated value of 100 pct of the theoretical density was taken to represent the resistivity value characteristic for the respective boride or carbide type.

Chemical analyses on hot pressed samples were made periodically to insure that the desired composition was maintained after hot pressing.

Density measurements were made using the immersion method. After completion of physical testing, such as electrical resistivity and density determinations, specimens were crushed to through 200 mesh and examined by X-ray diffraction with a Norelco Recording Spectrometer, using CuKα radiation.

Results

The results of this work have been summarized in Tables II through XI. In each of these tables, the details and processing conditions for individual experiments are described, each table dealing with some compositions of one of the ten metal-carbon-boron systems that were examined during the course of this investigation. Complete equilibrium conditions could not always be obtained for all experiments, as described below, because of certain experimental difficulties. However, the trend and direction in which reactions and transformations will move is clearly indicated by the results obtained and tabulated in the tables.

System Ti-C-B (Table II). In addition to the phase TiB_2, as reported by Norton and coworkers,[7] Greenhouse, Accountius, and Sisler[8] recently reported the existence of a TiB_{12}, suspecting TiB_{10}. Experiments in connection with the system Ti-C-B were therefore designed to detect boride phases higher than the diboride, and boron additions to either the metal or carbide were calculated accordingly. In studying the results tabulated in Table II, it becomes apparent that in practically all cases, the diboride of titanium was a major component of powder mixtures involving any combination of Ti-C-B, if hot pressing was carried out in the temperature range approximately 1400° to 2700°C. Titanium carbide reacted with boron or boron carbide in this temperature range, and the metal, in turn, reacted with boron carbide to form the relatively stable diboride. Mixtures of TiB_2 and B_4C could be heated to high temperatures without any indication of reaction or new compound formation.

Mixtures of titanium and boron were also hot pressed at 2300°C. X-ray diffraction examination of these specimens showed that considerable amounts of Ti_3B_4 were present. The pattern of lines assumed to belong to the phase Ti_3B_4 is very similar to that of W_2B_5 and these two structures are undoubtedly isomorphous. During the course of this work, the pattern of lines reported by Greenhouse, Accountius, and Sisler[8] could never be obtained.

TiB_2 was melted at approximately 2790°C. A TiB_2 as reported by Ehrlich,[9] but with larger unit cell dimension (a = 4.26A as against 4.20A reported by Ehrlich) could also be produced at a temperature below that for which the diboride formation was

Tables II, III, and IV

No.	Metal	Starting Mixture, Wt Pct C	Starting Mixture, Wt Pct B	Starting Mixture, Wt Pct B_4C	Hot Pressing Temperature Employed, °C	Phases Present in Hot-Pressed Powder Mixtures, as Identified by X-ray Diffraction
Table II—System Ti-C-B						
1	65-TiH$_2$	14	21		1450, 1650, 2100	TiB_2, C
2	51-TiH$_2$	11	38		1450, 1700, 2100, 2200	TiB_2, B_4C
3a	57-TiH$_2$		43		2700 + normal cool	TiB_2
3b	57-TiH$_2$		43		2700 + quench	TiB_2
3c	57-TiH$_2$		43		2790 — melt + normal cool	TiB_2
3d	57-TiH$_2$		43		2790 — melt + quench	TiB_2
3e	57-TiH$_2$		43		2300	Weak TiB_2, Ti_3B_4
4	82-TiH$_2$		18		2300	Weak TiB_2, Ti_3B_4
4a	82-TiH$_2$		18		1150, 1250	Ti_3B_4, TiB
5	73.5-TiC		26.5		1500, 1900, 2300	TiB_2, C
6	56-TiC			44	1500, 1900, 2150	TiB_2, B_4C
7	67-TiB$_2$			33	1600, 2150	TiB_2, B_4C
Table III—System Zr-C-B						
8	76-ZrH$_2$	9	15		1300, 1700, 2400	ZrB_2, C
8a	89-ZrH$_2$		11		1100	ZrB
9	55-ZrH$_2$	7	38		1300, 1700, 2350	ZrB_2, B_4C
10	88.5-ZrH$_2$		11.5		1900, 2350	ZrB_2, ZrC
11	60-ZrH$_2$		40		1600, 1900, 2300	ZrB_{12}, trace ZrB_2
12	60-ZrC		40		1500, 2000	ZrB_2, B_4C
13	67-ZrC			33	1400, 2150	ZrB_2, B_4C, C
14	67-ZrB$_2$			33	2100	ZrB_2, B_4C
Table IV—System Ta-C-B						
15	90-TaH$_2$	3.5	6.5		1500, 2100, 2200	TaB_2, C
16a	90-TaH$_2$		10		2800	TaB_2, Ta_2B, Ta_3B_4
16b	90-TaH$_2$		10		3040 — melt	Ta_2B, weak TaB_2
17	90-TaH$_2$	3.2	4.8		1300, 2100, 2300	TaB_2, TaC
18	84.3-TaH$_2$		5.7		2300, 2900	Ta_2B, vs TaB_2
19	89.5-TaC		10.5		1500, 2100, 2350	TaB_2, C
20	67-TaC			33	1500	TaB_2, B_4C, C
21	67-TaB$_2$			33	2000	TaB_2, B_4C
22	67-TaB			33	2000	TaB_2, B_4C

Tables V, VI, and VII

No.	Starting Mixture, Wt Pct: Metal	C	B	B_4C	Hot Pressing Temperature Employed, °C	Phases Present in Hot-Pressed Powder Mixtures, as Identified by X-ray Diffraction
Table V—System Nb-C-B						
23	76-NbH_2	9	15		1500, 2000	NbB_2, C
24a	82.5-NbH_2		17.5		3000	NbB_2, trace NbB, C
24b	82.5-NbH_2		17.5		3180 — melt	NbB_2, trace NbB, C
25	82.5-NbC		17.5		1500, 2500	NbB_2, C
26	77-NbC			23	1500, 2100	NbB_2, B_4C, C
27	67-NbB_2			33	2000	NbB_2, B_4C, C
Table VI—System V-C-B						
28a	75-V	13.5	25		2780	VB_2, trace C
28b	75-V		25		2940 — melt	VB_2, some VB
29	63.5-V		23		2780	VB_2, C
30	82.5-V		17.5		2300	VB only
31	60-VB		40		2400, 2700, 2750	VB_2, some B_4C
32	100-VB				1150 — melt	VB, unchanged
33	74-VC		26		2400, 3010 — melt	VB_2, some VB
34	82.5-VC		17.5		2400	VB_2, C
35	67-VC			33	1500, 2100	VB_2, B_4C, C
36	67-VB_2			33	2100	VB_2, B_4C
Table VII—System Cr-C-B						
37	69.5-Cr	9.5	21		1500	CrB_2, C
38a	76-Cr		24		2000	CrB_2
38b	76-Cr		24		2780 — melt	CrB_2
39	73-Cr_3C_2		27		1600	CrB_2, C
40	67-Cr_3C_2			33	1700	CrB_2, B_4C, C
41	77-CrB			23	1500, 2000	CrB_2, B_4C, C
42	67-CrB_2			33	1700, 2100	CrB_2, B_4C, C

observed. Nitrogen and carbon analysis, as well as X-ray intensity measurements, eliminated the titanium carbide or titanium nitride possibilities. In addition to this face-centered cubic structure belonging to TiB, a new Ti_3B phase believed to be tetragonal in structure was detected.

Whenever any of the three new phases, apparently Ti_3B, TiB, or TiB_2 were obtained, the specimens contained relatively small amounts of carbon, if any at all. A detailed examination of structures appearing to be those of a Ti_3B, TiB, and TiB_2 is being carried out at this time and will be reported on in a separate paper by Post and Glaser.

System Zr-C-B (Table III): ZrB_2 has recently been reported by Post and Glaser[7] and boron additions to either the metal or zirconium carbide were calculated accordingly. From the data of Table III, it is apparent that ZrB_2 can be produced only in the absence of relatively large amounts of carbon. This means, that whenever zirconium containing some graphite, or zirconium carbide, are combined with either boron, or boron carbide, ZrB must be the end result. Therefore to produce ZrB_2, the carbon content had to be kept very low. X-ray diffraction of the hot pressed sample (No. 11) showed the presence of both ZrB and ZrB_2. It is believed that some of the boron added to zirconium was lost during processing so that there was not enough boron to form a sample consisting of only ZrB_2. No reactions or new compound formations could be observed for hot pressed B$_4$C-ZrB$_2$ mixtures, indicating a certain stability of the diboride in the presence of boron-carbide. With only small amounts of graphite in ZrB_2-B mixtures ZrB_2 can be formed. ZrB_2 was melted without any signs of decomposition.

System Ta-C-B (Table IV): Any combination of the elements Ta-C-B, if mixed and hot pressed at temperatures between 1500° and 2900°C, contained TaB_2 as a major component. However, at temperatures above 2900°C, TaB_2 appeared to have a tendency toward decomposition in favor of TaB and B. On the basis of the X-ray evidence collected in connection with experiments 16a and b (Table IV), mixtures of tantalum and boron, if hot pressed at or above 2900°C, will contain substantially TaB_2. Excess boron probably combined with the graphite, introduced through the use of graphite dies, to form B$_4$C on cooling. However, at temperatures below 2900°C, TaB_2 appeared to be a more stable phase than TaB, since the presence of graphite in most cases interfered with a TaB formation in favor of TaC and TaB_2. TaB_2/B$_4$C mixtures could again be heated to a high temperature without any evidence of reaction or instability of either phase. The combination of TaB with B$_4$C or B always resulted in the formation of the diboride. No boride phase higher than TaB_2 was found. In the presence of boron or boron carbide, TaC reacted at temperatures below 2900°C, forming the diboride plus carbon.

System Nb-C-B (Table V): In the presence of carbon, and if heated to temperatures between approximately 1500° and 3000°C, the diboride was the major component of hot pressed Nb-C-B mixtures. NbB reacted in the presence of large amounts of carbon, boron, or boron carbide to form the diboride plus carbide. At temperatures close to the melting point of the diboride, substantial amounts of monoboride appeared. This fact seemed to indicate that while the monoboride is relatively unstable in the presence of boron, boron carbide, or carbon in the range 1450° to 2900°C, it can be found at temperatures in excess of 2900°C at the expense of the diboride. NbB_2/B$_4$C mixtures retained their composition ratio if heated and pressed at approximately 2100°C.

System V-C-B (Table VI): VB has been recently reported[8] and can be produced without any difficulty in the absence of larger amounts of carbon. If considerable quantities of graphite are present, any combination of V-C-B will result in the diboride and carbide. While X-ray diffraction showed VB to have retained its structure if heated to its melting point,

Tables VIII, IX, X, and XI

No.	Starting Mixture, Wt Pct: Metal	C	B	B_4C	Hot Pressing Temperature Employed, °C	Phases Present in Hot-Pressed Powder Mixtures, as Identified by X-ray Diffraction
Table VIII—System Mo-C-B						
35	90-Mo	5.5	4.3		1450	Mo_2B, Mo, Mo_2C
35b	90-Mo	5.5	4.5		1750	Mo_2B, Mo_2C, some Mo
35c	90-Mo	5.5	4.5		2050	Increased Mo_2C, decreased Mo_2B
44	78.5-Mo	4.5	17		1700, 2100	MoB_2, C
45	80-Mo			20	1900, 2100	MoB_2
46	82-Mo_2C		18		1600, 2100	MoB_2, C
47	66-Mo_2C			33	1800	MoB_2, B_4C, C
48	66-Mo_2B			33	1800, 2000	MoB_2, B_4C, C
49	66-MoB			33	1800	MoB_2, B_4C, C
50	66-Mo_2B			33	1600	MoB_2, B_4C, C
Table IX—System W-C-B						
51	90-W	3.3	6.7		1500, 1700	WB, WB*, C
52a	88.5-W		11.5		2600	W_2B_5, C
52b	88.5-W		11.5		2980—melt	W_2B_5, C
53	72-W			23	1900	W_2B_5, B_4C, C
54a	87-WC		13		1800	W_2B_5, WC, B_4C
54b	87-WC		13		2100	W_2B_5, B_4C, C
55	77-WC			23	2100	W_2B_5, B_4C, C
Table X—System Fe-C-B						
56	74.5-Fe	5.5	20		1400	FeB, C
57	75-Fe_3C		25		1500	FeB, C
58	71-Fe_3C			29	1500	FeB, B_4C, C
59	67-FeB			33	1500	FeB, B_4C, C
Table XI—System Th-C-B						
60	59-Th	7	24		1500, 2100	ThB$_4$, B_4C, ThO_2
61	57-Th		27		1500, 2100	ThB$_4$, ThO_2

the diboride, if heated to its melting point, showed evidence of decomposition toward the monoboride. The carbide phase reacted in the presence of boron or boron carbide to form VB_2, while VB_2/B_4C mixtures did not show any sign of reaction or new compound formation if heated to about 2100°C and hot pressed.

System Cr-C-B (Table VII): Both Cr_3C_2 and CrB reacted to form CrB_2, if boron or boron carbide were added and the mixtures were hot pressed at temperatures above 1350°C. CrB was not decomposed at temperatures close to its melting point. The monoboride was stable in the presence of carbon and could also be produced in graphite containers even at lower temperatures. An instability of this monoboride existed only in the presence of boron or boron carbide. A hot pressed mixture of boron carbide and CrB_2 retained its original composition ratio.

Table XII. Electrical Resistivities of Some Metal Borides

Boride Phase	Electrical Resistivity in Microhm-cm
ZrB_2	9.2-16*
ZrB_{12}	About 100*
TaB_2	15.5*
TaB	About 40*
Ta_3B_4	About 100*
TaB_2	68*
NbB	64.5*
Nb_3B_4	32*
VB	35*
VB_2	16*
MoB	50*
Mo_2B_5	22.5*
CrB	64*
CrB_2	21*
W-B	About 21*

* The values for the electrical resistivity of these boride phases were determined in this laboratory. They are approximate values, since minor impurities, such as carbon as well as some porosity, will influence the accuracy of the values reported above.

System Mo-C-B (Table VIII): If Mo or Mo_2C were combined with boron or boron carbide additions calculated to produce either Mo_2B or MoB_2, both phases were obtained upon hot pressing of such mixtures at temperatures between 1400° and 1800°C. The Mo-C-B system yields boride phases lower than the diboride, and is in this respect very similar to the system Cr-C-B, where a boride phase lower than the diboride could be formed in the presence of carbon. However, Mo_2B decomposed at temperatures above approximately 1950°C, Fig. 1. In the presence of carbon, the molybdenum of such a decomposed Mo_2B phase combines with carbon to form Mo_2C. Mo_2B and MoB were readily transformed in the presence of B or B_4C to form the higher boride, MoB_2, the high temperature modification of the phase Mo_2B.

Molybdenum diboride was found to be stable at very high temperatures, and checked up to 2100°C. According to Steinitz,† MoB_2 melts undecomposed.

† Private communication.

X-ray diagrams of hot pressed and quenched Mo_2B_5-B_4C mixtures showed the two components MoB_2 and B_4C without any shift in lines.

System W-C-B (Table IX): A new compound WB*, a high temperature modification of WB and isomorphous with MoB* (beta)[7] was found to exist above approximately 1800°C.

Any phase known to exist for the system W-B can be produced during the hot pressing of any combination of W-C-B. Wolfram carbide was reacted with both boron or boron carbide and formed any wolfram-boride phase at hot pressing temperatures in excess of 1450°C. This transformation proved to be somewhat "sluggish," and the last traces of wolfram carbide could be eliminated only by raising the hot pressing temperature to approximately 2100°C. W_2B_5 appeared to melt undecomposed at 2980°C, and was

stable if heated up to 2000°C in combination with B_4C.

System Fe-C-B (Table X): FeB is the most stable phase of the system Fe-B. Both iron-carbide and the metal iron readily form the compound FeB, if combined with boron or boron carbide and hot pressed at approximately 1300°C. The fact that FeB is stable in the presence of B_4C was borne out by the data obtained on hot pressed mixtures of FeB and boron carbide. No carburization or new compound formation took place when such mixtures were hot pressed at about 1450°C.

System Th-C-B (Table XI): The stable boride phase of the system Th-B is ThB_6. Although enough carbon was added to permit a possible carbide formation, ThB_6 was in all cases formed, the hot pressing temperature of formation for this compound was about 1350°C.

ThO lines were found on all spectrometer charts, a fact which is not surprising considering the well-known stability of thoria crucibles in graphite at relatively high temperatures.

Before closing the detailed discussion of the various metal-carbon-boron systems that were investigated here, it seems well to point out that although X-ray diffraction work proved to be the ideal tool for this type of study and in connection with phase identification, electrical resistivity measurements also proved very helpful in the quick identification of the major components present in a given specimen. Porosity, graphite and minor components present in hot pressed samples will affect electrical resistivity values and sometimes strongly influence the accuracy of results. Borides, and especially the diborides are better conductors than their corresponding carbide phase, the order of magnitude of the difference in electrical resistivity being approximately a factor of three.

Electrical resistivity values of hot pressed powder mixtures can therefore be used to identify the predominant phase without destruction of the specimen. In Table XII some electrical resistivity values for various boride phases have been reported.

Discussion of Results

It was the purpose of this paper to demonstrate the effect of carbon on the formation of certain boride phases, as well as the effect of boron on the stability of certain carbide phases.

Boride phases have proved to be, in general, more stable than their respective carbides. Any combination of metal-carbon-boron will, if hot pressed as a powder mixture, yield a boride phase. Regardless of the starting combination of the metal, carbon, and boron powders, whether or not these three are present in free or combined form, after hot pressing or heating to temperatures above approximately 1350°C, any mixture of this type will contain a metal boride phase as a major component.

Independent of the proportions in which the metals Ti, Zr, V, Ta, and Nb are mixed with either boron and carbon or boron-carbide powders, the mixture if hot pressed below about 2850°C always contained the diboride of the respective metal as a major component. The amount of diboride present was governed by the amounts of boron or boron carbide added. Excess metal or boron over the diboride combined with carbon. All possible boride phases were obtained upon hot pressing of Cr-C-B mixtures.

For the system Mo-C-B, three boride phases can be obtained upon hot pressing at relatively low temperatures. They are Mo_2B, MoB, and MoB_2. Mo_2B decomposed at approximately 1950°C, and the molybdenum combined with carbon upon decomposition of Mo_2B. Mo_2B and MoB reacted with either boron or boron carbide to form the higher boride, MoB_2, a high temperature modification of Mo_2B. MoB_2 can be considered the most stable compound of this system, since excess boron over this diboride combined with carbon, rather than react with MoB_2. MoB_2 melts undecomposed.

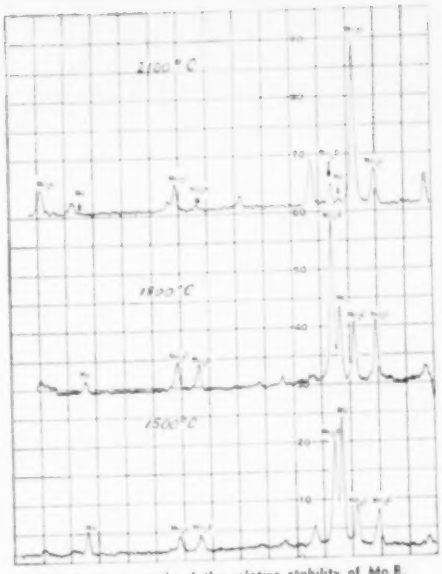


Fig. 1—X ray study of the relative stability of Mo_2B

The system W-C-B behaved very similarly to the system Mo-C-B. Again any boride phase known to exist for the system W-B could be obtained and depended only on the amount of boron added to either the metal or the carbide WC. W and WC reacted in the presence of boron carbide to form a wolfram-boride phase. A new high temperature modification of the monoboride WB, and WB^* phase, was found and is isomorphous with MoB^* (beta).

Any combination of the metals iron and thorium with boron and carbon or boron-carbide upon hot pressing resulted in the formation of the stable borides FeB and ThB_6, respectively.

It could generally be observed that the carbides of all metals that were studied here (Zr, Ti, Cr, V, Ta, Ni, Fe, W, Mo, and Th) were readily transformed to form boride phases in the presence of boron or boron carbide.

For the system Ti-B two new compounds, a tetragonal Ti_2B and Ti_3B_4, this latter phase being isomorphous with W_3B_4, were found. The existence of a controversial face-centered cubic monoboride TiB could definitely be confirmed.

For the system Zr-B a new phase of formula ZrB, which was found to be isomorphous with TiB was found. This monoboride ZrB as well as the phase ZrB_2 could only be produced in the absence of large amounts of carbon. In the presence of carbon, either the metal carbide or boron carbide were formed provided the diboride was satisfied with regard to either the metal or boron supply.

Table XIII. Summary of Results

M	MB_2	M_3B_4	M_5B_6	MB	M_3B_2	MB_4	M_2B_5	MB_6
Ti	U[1]			U		S	U[1]	
Zr				U[1]		S		U*
Hf								
V				U		Sd		
Nb	U			U	U	Sd		
Ta	U			U	U	Sd		
Cr	S	S		S	S	S		
Mo	S	S*		S*		S*	S	
				S				
W	S			S*			S	
				S				
Fe	U			S				
Th							U	S

U can be produced only in the absence of carbon.
S can be obtained regardless of amount of carbon present.
* Stable at high temperature only.
d. Decomposed on melting to form the monoborides plus boron.
—other diborides (fourth and sixth groups) did not decompose.
† New phases obtained by this investigation.
Note: Compounds of the same formula are not necessarily isomorphous.

When metal boride phases other than the stable borides, (the diborides of Zr, Ti, V, Nb, Ta, Mo, and Cr, or the phases FeB, ThB_4, and WB_4) were combined with boron and carbon or boron carbide, the stable boride phase, usually the higher B-content phase, was found in such mixtures after hot pressing. However, the hot pressing temperature could not be higher than about 200 C below the melting points for the borides VB_2, NbB_2, and TaB_2, since the diborides of Nb, V, and Ta have been found to decompose at certain temperatures, forming the monoborides plus boron or boron carbide instead.

The monoborides of Ta, Ti, Nb, V, and Cr could be readily produced provided care was taken to keep the carbon content to a minimum.

The electrical resistivity of some metal borides was measured on hot pressed samples that were between 90 and 100 pct of their calculated X-ray density. The electrical resistivity of the diborides was found to be lowest of all the borides for a particular system metal-B, and about half that of the monoborides.

Summary

An overall picture of the results obtained during the course of this work is given in Table XIII. This table summarizes the results as follows:

It was found that boride phases are in general more stable than their respective carbides. Any combination of metal-carbon-boron will, if hot pressed, yield a boride phase. This is true regardless of the previous state or combination of the boron or carbon. In the presence of relatively large amounts of carbon, this carbon competes with boron and boride phases of lower stability in ordinary temperature ranges. Here the MeB phase will be formed for metals of the fourth and fifth groups. Combinations of metals of the sixth group with carbon and boron will result in the formation of any of the phases known to exist for the respective metal-boron system.

In the absence of carbon, the phase formed for metals of the fourth and fifth groups depended only on the amount of boron present. Very small amounts of carbon and up to about 0.5 pct by weight did not seem to interfere with the normal formation of boride phases for these metals. Close to the point at which melting of the diborides of the metals of the fifth group occurred, X-ray diffraction studies showed the appearance of patterns identified as belonging to the respective monoborides. This behavior was tentatively interpreted to indicate the decomposition of these diborides at very high temperatures and could not be observed for the diborides of any other group that were investigated here.

Boride phases of the same formula are not necessarily isomorphous. As an example, four different structures can be obtained for the monoborides alone. Thorium boride phases of formula ThB_4 and ThB_6 were obtained. This type of phase, of formula MeB_4 or MeB_6, could not be found for any other transition metal-boron system. A variety of new phases that had not been reported in the literature to date were found. These included Ti_3B_4, Ti_2B_5, ZrB and WB*. The diborides were generally observed to be better conductors than the monoborides of the same metal.

Acknowledgment

A portion of this work was carried out under the sponsorship of the Office of Naval Research. The author wishes to thank this agency for permission to publish this paper. Thanks are also due to Paul Schwarzkopf, President, of American Electro Metal Corp., and to John T. Norton, of Massachusetts Institute of Technology, for valuable suggestions and helpful discussions. The cooperation of members of the staff of the American Electro Metal Corp., and especially that of George Stern, is also gratefully acknowledged.

References

[1] F. W. Glaser: *Powder Metallurgy Bull.* (1951) **6**, 1, pp. 51-54.

[2] R. Steinitz: *Powder Metallurgy Bull.* (1951) **6**, 1, pp. 54-56.

[3] J. A. Nelson, T. A. Willmore, and R. C. Womeldorph: Refractory Bodies Composed of Boron and Titanium Carbides Bonded with Metals. Presented at the Ninety-Ninth Meeting of the Electrochemical Society, Washington, D. C. April 8-12, 1951.

[4] E. R. Honak: Ueber Hochschmelzende Boride der Uebergangsmetalle. Thesis, Techn. Hochschule Graz. 1951.

[5] L. Andrieux: *Annales de Chimie* (1929) **12**, p. 423.

[6] J. T. Norton, H. Blumenthal, and S. J. Sindeband: Structure of Diborides of Titanium, Zirconium, Columbium, Tantalum and Vanadium. *Trans.* AIME (1949) **185**, pp. 749-751; JOURNAL OF METALS (October 1949).

[7] H. M. Greenhouse, O. E. Accountius, and H. H. Sisler: *Journal* A.C.S. (1951) **73**, p. 5086.

[8] P. Ehrlich: *Angew. Chem.* (1947) **59**, p. 163; *Ztsch. anorg. allgem. Chem.* (1949) No. 1, p. 259.

[9] L. H. Andersson and R. Kiessling: Binary Systems of Boron with Chromium, Columbium, Nickel and Thorium, etc. *Acta Chem. Scand.* (1950)**4**, p. 160.

[10] B. Post and F. W. Glaser: Crystal Structure of ZrB_{12}. To be published in *Trans.* AIME, JOURNAL OF METALS.

[11] H. Blumenthal: To be published in *Journal* A.C.S.

[12] R. Kiessling: The Binary System Zirconium-Boron. *Acta Chem. Scand.* (1949) **3**.

[13] R. Kiessling: Borides of Tantalum. *Acta Chem. Scand.* (1949) **3**, pp. 605-615.

[14] L. Brewer, D. L. Sawyer, D. H. Templeton, and C. H. Dauben: *Journal* Amer. Ceramic Soc. (1951) **34**, No. 6.

[15] R. Kiessling: Crystal Structures of Tungsten and Molybdenum Borides. *Acta. Chem. Scand.* (1947) **1**, pp. 893-916.

[16] *Metals Handbook*, (1951) A.S.M. Cleveland.

[17] C. Agte and K. Moers: *Ztsch. anorg. allgem. Chem.* (1931) **198**.

[18] R. Steinitz: The System Mo-B. JOURNAL OF METALS (February 1952) p. 148.

[19] B. Post and F. W. Glaser: Unpublished.

Lead-Uranium System

by R. J. Teitel

The Pb-U system has been investigated by X-ray, thermal, and microscopic analyses. Two pyrophoric intermetallic compounds were found; UPb_3 and UPb. The crystallographic structure of UPb_3 is reported. A phase diagram was drawn for the system showing three eutectic and one syntectic reaction.

AS a result of the interest in uranium metallurgy, the Pb-U system has been investigated. Practically no quantitative data appears in the literature concerning this system.

Chips were machined from bars of high-purity uranium obtained from Ames Laboratory and the lead was 99.9 pct high-purity grade from Belmont Smelting & Refining Co. The chips were pickled in a dilute solution of nitric acid, washed in water and then alcohol, and dried prior to use for alloy preparation. The lead was simply sheared from the pig with no chemical treatment.

Lead and uranium were placed in graphite crucibles and loaded into an induction furnace. In order to insure good alloy formation, the lead was loaded above the uranium to wash the uranium chips into the melt. After the charge was held at the desired preparation temperature for 15 to 30 min, it was allowed to cool in the crucible.

The entire melting operation was accomplished in an atmosphere of helium (double charcoal refined grade with no further treatment). The procedure was to outgas the furnace by first evacuating it to 10^{-4} mm Hg, admitting helium to 8 psi gage and sealing the furnace off.

An optical pyrometer focused on the charge through a hole in the crucible cover was employed for thermal measurements. Usually a 50° to 70°C correction had to be added to the instrument value.

The most suitable alloy preparation temperature range was found between 1220° and 1280°C. The reason for this is explained by the phase diagram, Fig. 7. Above this temperature range two liquids separate preventing alloy formation upon cooling at a reasonable rate. On the other hand, below this range the uranium was coated with a layer of both compounds and the rate of reaction was diminished by diffusion processes. The fastest reaction rate occurred in this narrow range of temperature because only UPb coats the uranium and it evidently does not protect the uranium as well as UPb_3.

R. J. TEITEL is Associate Metallurgist, Brookhaven National Laboratory, Upton, L. I., N. Y.

Discussion on this paper, TP 3213E, may be sent, 2 copies, to AIME by June 1, 1952. Manuscript, July 23, 1951; revised, Jan. 24, 1952. New York Meeting, February 1952.

The work reported in the paper was performed under the auspices of the Atomic Energy Commission.

Apparatus and Procedures

The development of apparatus and techniques was determined by the peculiar properties of the alloys. All the alloys were pyrophoric, and, consequently, the alloys had to be protected from oxidation by handling them in a dry box or inert atmosphere furnaces. Other operations performed outside of this equipment had to be done as quickly as possible.

Thermal analyses were conducted in a furnace and arrangement similar to that described by the author.[1] Graphite crucibles having a thermocouple well in the bottom were used to contain the prepared alloy, while a helium atmosphere protected the melt from oxidation. The furnace was outgassed by pumping a 10^{-4} mm Hg vacuum until the furnace had been heated to 400°C. Then helium was admitted and the furnace sealed under 8 psi gage pressure.

Chromel-alumel thermocouples were used for thermal analysis and the accuracy of thermal measurements was judged to be ± 5°C. At first, an attempt was made to use platinum-platinum-rhodium thermocouples, but evidently lead vapors attack it at high temperatures forming low melting alloys. These lead vapors had direct access to the thermocouple because the graphite crucible was porous.

A differential temperature control was used to regulate thermal analyses. The thermal gradient across an alundum tube placed between the windings and the crucible was maintained constant by a controller.

Table I. X-Ray Diffraction Data UPb_4

Cell — Cubic
a_0 = 4.793 A**
Number of atoms per cell = 4***
Density = 12.98 g per cc

Plane h k l	I*	d (A)**	d (calc.)
111	M	2.74	2.77
200	M+	2.37	2.40
220	M	1.68	1.69
311	S	1.44	1.44
222	W	1.38	1.38
400	W+	1.19	1.20
331	M	1.10	1.10
420	M+	1.069	1.071
422	S	0.9757	0.9779
511,333	S	0.9212	0.9220
440	M	0.8468	0.8469
531	S	0.8097	0.8098
600	S	0.7984	0.7985

* Relative intensities for CuK_α
** Corrected from Kx to A by factor 1.00202
*** Calculated from an estimated density (eq 1)
S means strong, M, medium, W, weak.

Rates from 1° to 5° per min were usually employed.

Debye-Scherrer X-ray specimens were prepared by crushing the alloy below 100 mesh in the dry box, and sealing the powder in a thin walled quartz capillary (0.025 in. in diam). A 2 mil aluminum foil was placed over the film to filter out the uranium M-radiation excited by CuK_α radiation.

Microscopic specimens were polished under silicone oil on successive papers to 4/0 grit. If the uranium content was below 10 pct U, the specimen was finished on the polishing wheel. The oil delayed oxidation but did not prevent it. Therefore, examination of the sample immediately after preparation was requisite for interpretable micrographs.

Alloys were analyzed chemically by two methods. If the concentration was below 1 pct U, a polarographic method was employed. Other alloys were analyzed both for lead and uranium by dissolving the alloy in nitric acid. Lead was weighed as lead sulphate after several sulphuric acid fuming operations. Uranium was reduced in a Jones reductor and later determined by titration with citric acid.

Experimental Results

The diagram for the U-Pb system appears in Fig. 7. After each of the solid phases has been described, the metallographic, thermal analyses, and thermal treatment results will be presented for the entire diagram. All compositions will be given in weight percent unless otherwise indicated.

Lead Phase: Since no appreciable change in the crystallographic dimensions of lead had been observed and apparently the eutectic composition between lead and UPb_3 contained little uranium (less than 0.1 pct), the solubility of uranium in solid lead was considered to be essentially nil. The established melting point for lead (327°C) was used.

Uranium Phase: Similarly, the eutectic between uranium and the first compound was located very close to pure uranium (99.6 pct U). Moreover, the addition of lead to uranium had no effect on the allotropic transformation temperatures of uranium. Therefore, it has been concluded that there is very little solid solubility of lead in uranium. Thermal analyses of uranium indicated that the α-β transformation occurred at 640°C, the β-γ transformation at 765°C, and the melting point at 1130°C, which are in close agreement with those listed by Katz and Rabinowitch.[7]

UPb_3 Phase: One of the two intermetallic compounds found in this system was located metallographically at 25 atomic pct U. It is moderately pyrophoric and crumbles to powder (UO, and Pb) on exposure to air. Its melting point was not definitely established, but it occurs around 1210° to 1250°C.

X-ray diffraction data for this compound are summarized in Table I. Owing to the pyrophoric nature of the compound, the density was not found experimentally. It was estimated by using eq 1, which assumes that the atomic volume of bismuth and uranium is not affected by alloy formation:

$$\frac{M_U + 3M_{Pb}}{\frac{M_U}{D_U} + \frac{3M_{Pb}}{D_{Pb}}} = D_{UPb_3} \qquad [1]$$

where M and D are the atomic weight and density of the elements indicated by the subscript respectively. This method for estimating the density of intermetallic compounds has been tested on many known metallic systems and found adequate, especially when the cell is small as in the case of UPb_3. Consequently, calculations based on this equation showed the compound to have four atoms per cell. This seemed reasonable since there are four atoms per intermetallic molecule and four points of symmetry in the cubic cell. However, the question whether the atoms are arranged in an ordered or random fashion remains to be answered, since the atomic scattering factor for uranium is very similar to that of lead. Consequently, the cell has been classified cubic for the present.

The size of the cell was determined accurately from the high angle lines of a Debye-Scherrer pattern. When this value is used to calculate the other interplanar distances, the deviation is significant for the low angle reflections. This is probably due to the high absorption of the specimen.

Since the lattice parameter of UPb_3 in alloys containing less uranium than the stoichiometric composition was the same as that in alloys of high uranium content, it was doubtful whether the compound extended over an appreciable range of compositions.

UPb Phase: The composition of this compound was estimated from the microstructure. It was calculated by measuring the volume percent of compound and UPb_3-UPb eutectic, knowing the composition of the eutectic, estimating the density relationships and applying the "lever-arm" principle.

Alloys close to the compound composition separated into two liquids when heated above 1280°C. In accord with this, a syntectic transformation was found at that temperature.

The extremely pyrophoric character of UPb prevented adequate X-ray analyses to determine its crystal structure.

Microscopic Results: Figs. 1 through 6 are examples of the microstructure of various Pb-U alloys prepared at 1250°C and cooled in the furnace. They are not as clear as the usual micrographs, but they are the best that could be obtained from these pyrophoric alloys. Some of the indicated compositions have been adjusted to take into account the segregation found in many alloys.

The microstructure of an alloy containing approximately 10 pct U, Fig. 1, is typical of alloys in the range of compositions 0 to 15 pct U. UPb, (light areas) usually crystallized from the melt in the angular forms. The gray background is the Pb-UPb_3 eutectic, and the dark areas are pits from which the UPb, had oxidized during specimen preparation. Figs. 2 and 3 are the structures of the top and bottom portions respectively

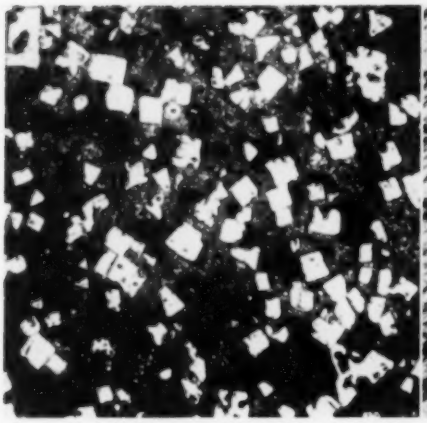


Fig. 1—10 pct U-Pb alloy as solidified. Light cubic particles of UPb_3 in gray UPb_3-Pb eutectic, dark areas are pits. Air etched. X150.

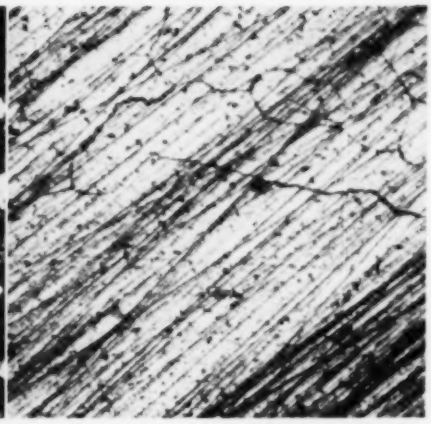


Fig. 2—30 pct U-Pb alloy as solidified showing UPb_3-UPb eutectic composed mainly of UPb_3. Air etched. X150.

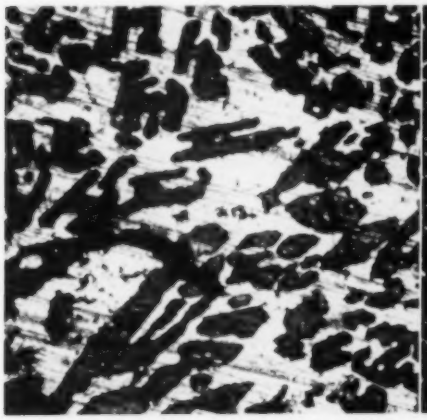


Fig. 3—35 pct U-Pb alloy as solidified. Dark primary grains of UPb in UPb-UPb_3 eutectic. Air etched. X150.

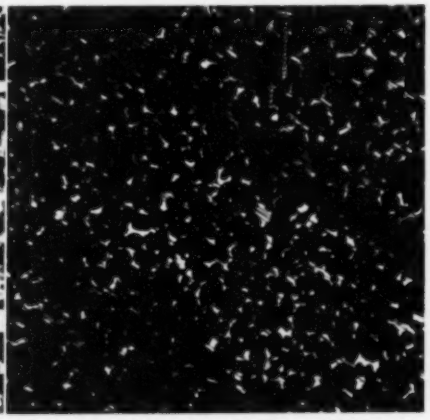


Fig. 4—45 pct U-Pb alloy as solidified from 1250° C. Dark primary grains of UPb in UPb-UPb_3 eutectic. Air etched. X150.

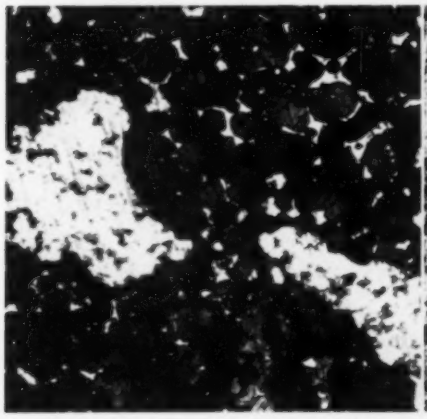


Fig. 5—Approximately 70 pct U-Pb alloy as solidified from 1250° C. Gray UPb primary grains in light UPb-U eutectic, black areas are pits. Air etched. X150.

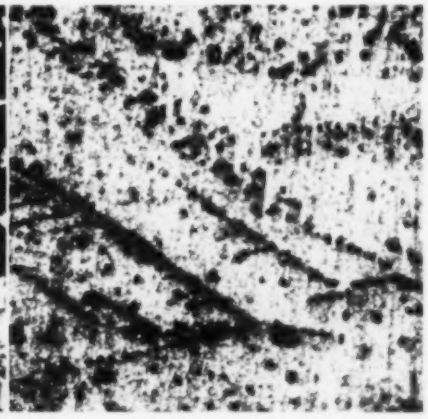


Fig. 6—98.4 pct U-Pb alloy as solidified. Dark dendrites of primary UPb in UPb-U eutectic. Air etched. X150.

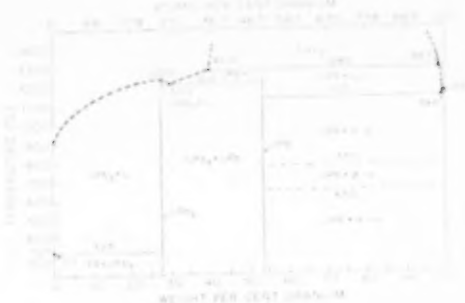


Fig. 7—U-Pb phase diagram. Accuracy of thermal measurements is ± 5°C.

of an alloy ingot showing settling. Fig. 2 is the eutectic structure between UPb and UPb_3. Chemical analysis of a section next to this specimen placed the composition of this eutectic at 30 pct U. The lower portion (Fig. 3) consisted of UPb (dark grains) and eutectic (light area) which is almost entirely UPb.

More primary grains of UPb were evident in the structure of an alloy containing 45 pct U, Fig. 4. In Fig. 5, UPb is shown with a eutectic of high uranium content. This is in accord with the fact that dendrites of UPb appeared in a structure of an alloy containing 1.6 pct Pb, Fig. 6.

Alloys containing above 40 pct U separated into two liquids above 1280°C. The top and bottom portions had microstructures similar to Figs. 3 and 6 respectively.

Thermal Analysis Results: Thermal analysis results are summarized in Table II. They show that the Pb-UPb_3 eutectic temperature is 325°C. The thermal arrest found in alloy 201-46 at 1215°C was attributed to the UPb-UPb_3 eutectic.

In order to establish the syntectic temperature, several alloys containing over 40 pct U were prepared and examined for homogeneity. Then a portion of each alloy was subjected to a thermal analysis while heating into the region of liquid immiscibility (above 1280°C). Afterward the specimen was cooled and analyzed thermally. Providing enough of the uranium-rich phase was retained, transformations associated with uranium were found upon cooling. Otherwise, only those of the lead-rich phase were noted. For example, alloy 259-50 was heated and two transformations occurred at 1210° and 1287°C; upon cooling at 1210°, 767°, and 640°C. After the alloy was unloaded a hard button was found on the bottom showing separation. The transformations were explained in the following manner: 1210°C, UPb_3-UPb eutectic; 1287°C, syntectic temperature; 760° and 640°C, the allotropic transformations in the uranium phase.

A thermal analysis of alloy 259-19 containing 99 pct U located the U-UPb eutectic temperature (1125°C) and showed that the allotropic transformations in pure uranium were not affected appreciably by 1 pct Pb. The resulting microstructure contained dendrites of UPb similar to those in Fig. 6. Therefore, the eutectic composition had to be greater than 99 pct U.

Liquid Immiscibility Limits: Alloys were prepared at 1250°C and examined for homogeneity. Then they were heated into the liquid immiscibility region and the separated sections were analyzed chemically. Sometimes the inhomogeneity in the resulting lead-rich section made it necessary to calculate the composition of this phase by knowing the weights and compositions of the original alloy and the uranium-rich section, which did not segregate as badly. A summary is given in Table III. No attempt was made to control the temperature at which equilibration occurred, because the chromel-alumel thermocouples were unreliable at these temperatures for long periods. As a result, the liquid immiscibility is reported to extend from 40 to 98.5 pct U.

Table II. Thermal Analyses Results for U-Pb System

Alloy No.	Composition* (Wt Pct U)	Transformation, °C
201-60	2	323
201-61	15	324
201-61	25	330
201-46	35	1215
201-46	45	1207
259-50 Original	61	1210 Separation
Top	61	767, 640 1287
Bottom	98.5	
259-63 Original	45	1210 Separation 1280
259-50 Original	45	1202 Separation 1277
259-19 Bottom	99	1125, 760, 654

* Accuracy in compositions ± 2 pct.

Table III. Liquid Immiscibility Limits

Alloy No.	Composition Pct U	
	Lead-Rich	Uranium-Rich
259-15	Segregated	98
259-30	41	98.5
259-70	45*	97.4

* Calculated.

Conclusions

All these data have been incorporated in the diagram shown in Fig. 7. There are two intermetallic compounds: UPb_3 and UPb. Both are pyrophoric, but UPb is more so than UPb_3. The crystal structure of UPb, is cubic (a_o = 4.791A) with four atoms per cell. It is not certain whether the atoms are ordered or random, since the atomic scattering factors for X-rays are very similar for both uranium and lead.

The system contains three eutectics and one syntectic. These reactions are summarized in the following formulas where the subscripts indicate the weight percent uranium: A eutectic at 325°C, $L_{2} \rightleftharpoons Pb + UPb_3$; another eutectic at 1210°C, $L_{45} \rightleftharpoons UPb_3 + UPb$; another eutectic at 1125°C, $L_{99.5} \rightleftharpoons UPb + U$ and a syntectic at 1280°C, $L_{45} + L_{98.5} \rightleftharpoons UPb$. The melting point of UPb, is still uncertain. It is probably between 1210° and 1250°C. No solid solutions were detected in the system.

Acknowledgments

The author wishes to thank all those at Brookhaven National Laboratory who contributed directly or indirectly to the completion of this phase diagram, in particular, W. Stapf for his assistance in preparing and treating the alloys, O. Kammerer and A. Cendrowski for their aid in metallography, A. Bartozak for his assistance in X-ray analyses, and R. W. Stoenner for chemical analyses. He also thanks D. H. Gurinsky for reading the manuscript and for his suggestions throughout the entire project.

References

[1] R. J. Teitel: Design for Equipment for Thermal Studies. *Review of Scientific Instruments* (1949) **20**, No. 8, pp. 575-578.

[2] Katz and Rabinowitch: *Chemistry of Uranium*, (1951) p. 149, New York. McGraw-Hill Book Co.

Viscous Creep of Gold Wires Near the Melting Point

by F. H. Buttner, E. R. Funk, and H. Udin

Gold wires, 5 mil in diam, are found to creep viscously up to approximately 5.5x10^7 dynes per sq cm around 1300°K. Beyond this point, an additional slip mechanism appears. The average coefficient in the viscous range at these temperatures is 18.9 ± 7x10^7 poises. This observation and other visual observations made during the experiments agree with Herring's predictions.

EARLY creep studies by Chalmers on single crystals of tin produced some of the first experimental evidence to suggest that metals deform viscously under very light stresses. That is to say, over a small initial stress range up to 150 g per sq mm, the single crystals of tin elongated at a rate proportional to the stress. The proportionality constant between strain rate and stress is by definition the coefficient of viscosity. Chalmers named this range of proportionality the microcreep range.

One of the first theoretical attempts to explain the microcreep phenomenon was given by Kauzman,[1] who applied Eyring's[2] general statistical mechanical theory of shear rates to creep data then available. From the rate theory, he deduced the general hyperbolic sine law for shear rate on the assumption that the distortion of the reaction path due to stress is negligible and that the system is an infinite continuum. In order to fit the available data to the equation, it was necessary to assume that creep occurs by shear of rather large blocks of material, rather than by an atomistic shear process as in diffusion. The size of the shear units was shown to increase with increasing temperatures and lower stress, or lower strain rates.

In applying the hyperbolic sine law equation to the microcreep data of tin, it was shown by Kauzman that the unit shear blocks became quite small, which suggested to him that microcreep might be a self-diffusion process. Making this an assumption, Kauzman reworked the rate theory and arrived at an equation where the shear rate is proportional to the stress. In the form of viscosity coefficient, the equation is:

$$\eta = \frac{\sigma}{S} = \frac{\lambda L k T}{2 q A l \Delta} \qquad [1]$$

where σ is the stress; S, the shear rate; λ, the distance in shear direction moved by flow units relative to one another in the unit process; L, the distance between layers of units of flow; T, the absolute temperature; k, Boltzmann's constant; qAl, a constant proportional to the size of flow units; and Δ, the diffusion coefficient $= \frac{kT}{h} e^{q_v/RT} = k_v \lambda^2$

Kauzman applied the expression to molten lead with a fair degree of success, the calculated viscosity being low by a factor of four. For solid lead the result is 5000 times too high. Taking $q = 1$, and $\lambda = \sqrt{A} = L = 2l$ = nearest neighbor distance, Udin, Shaler and Wulff[3] found the equation low by a factor of 10^7 for solid copper. On the basis of the discrepancy in lead, Kauzman indicated that microcreep is probably not a simple diffusion process of molecular shear units, but one involving preferential diffusion paths, or even that diffusion in solids does not involve shear at all.

Cottrell and Jaswon[4] treat the microcreep phenomenon on the basis of slow moving dislocations and apply it to Chalmers' data on tin with fair success.

Nabarro[5] suggested a microcreep model in which mass movement in the direction of pull is effected by the diffusion of holes. The tension on the crystal effectively creates a greater hole concentration at regions near the crystal surfaces perpendicular to

F. H. BUTTNER is Research Associate, and E. R. FUNK, Junior Member AIME, and H. UDIN, Member AIME, are Assistant Professors, Dept. of Metallurgy, Massachusetts Institute of Technology, Cambridge, Mass.

Discussion on this paper, TP 3277E, may be sent, 2 copies, to AIME by June 1, 1952. Manuscript, Sept. 7, 1951; revised, Dec. 27, 1951. New York Meeting, February 1952.

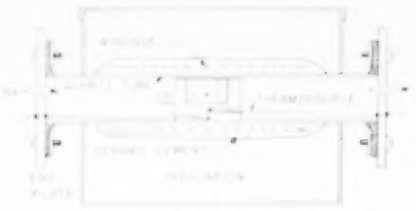


Fig. 1—Schematic diagram of quartz tube furnace

the pull than at the regions near the other crystal surfaces. This gradient causes the holes to diffuse away from the former regions to the latter regions. In the opposite sense, atom movement occurs in the other direction, which means that matter is moving from the sides of the crystals to the ends where the tension is being applied. This effectively produces elongation in the direction of pull. The Nabarro model serves quantitatively as well to explain Chalmers' observed elongations of tin single crystals, using domains containing diffusion paths to and from domain boundaries. However, the mechanism is rejected by its originator in that it fails to account for some features of limiting strain, and recoverable creep observed in microcreep of tin single crystals.

Herring,[7] however, used Nabarro's suggestion in analyzing the creep behavior of wires under light loads held at high temperatures. Small wires recrystallize and assume an equilibrium reed-like or bamboo grain structure when subjected to high temperatures. The grain boundary planes run straight across the wire essentially perpendicular to the wire axis. Thus the final structure consists of a stack of single crystals piled up to form a cylinder. The axis of each crystal is disoriented with respect to its neighbor, but Chalmers'[6] experiments show that orientation has no effect on microcreep, so the wire is in this respect the same as a single crystal. Herring treated this structure by means of an electrical analogue and arrived at a relation for viscosity:

$$\eta = 2kTRL/3BD\Omega, \qquad [2]$$

where L is the distance between grain boundaries; R, the radius of the grains; B, a constant, a function of L/R; D, the diffusion coefficient; and Ω, the atomic volume of the atoms.

This analysis cannot account for recoverable creep and limiting strain as seen in microcreep of tin.

Orowan[8] treats the problem of viscous flow in solids on the basis of an atomistic shear process which results in viscous deformation. The relation so derived is of the type:

$$\eta = \frac{kT}{C'} e^{-Q/RT} \qquad [3]$$

where k is Boltzmann's constant; T, the temperature, °K; Q, the activation energy of viscosity; R, the gas constant; and C' a constant.

Frenkel[9] in attempting to develop a theory of sintering arrived at essentially the same relation in eq 4:

$$\eta = \frac{kT}{DS} \qquad [4]$$

where $D = D_0 e^{-Q/RT}$ and $D_0 = C''/S$. Eq 4 is identical to Kauzman's viscosity equation if it is assumed that the single atom rather than the mosaic block is the unit of flow.

In the Udin, Shaler, and Wulff[1] experiments on copper, and in other experiments[2,3] on gold and silver, in which practically the same techniques were used, it was assumed that lightly loaded wires in those experiments deformed viscously. This assumption was necessary in order to allow a straight line to be drawn through the plotted points on the stress-stram axes. The strains plotted on the ordinate can also be thought of as average strain rate, since it took a given amount of time to effect the strain. In all cases, the points approximated a good straight line within experimental accuracy. Therefore, the assumption is a good one for these experiments. From the slope of this line, Udin, Shaler, and Wulff found an experimental value for the average viscosity. If it is assumed that the elongation and time interval in the initial transient creep is negligible compared to the overall creep, the above value for viscosity can be taken as the steady state viscosity of the second stage of creep. Computed in this way, the copper activation energy for viscosity is 59,000 cal per mol, which is in the range of reported values for activation energy of self-diffusion of copper. The relation used for this calculation was essentially eq 3.

Alexander, Dawson, and Kling[3] performed somewhat similar experiments on gold in order to determine the mechanism of its deformation in the low stress range. In their technique continuous strain measurements were made on the wires through a slit in the vertical chromium heating tube which surrounded a single wire loaded with tungsten weights. In this way strain rates were measured in all stages of creep. It is interesting to note that the strain vs. time curves reported by these authors show very small primary creep stages in lightly loaded specimens of gold. This experimental observation strengthens the above neglect of primary creep by Udin, Shaler, and Wulff in calculating the viscosity coefficient. Here again, the experimental points of second stage strain rate vs. stress approximate a good straight line. For this reason Alexander, Dawson, and Kling concluded that the mode of deformation is viscous. Using eq 3, the experimental values for activation energy viscosity of 48,000 cal per mol was found to be somewhat lower, but close

Table I. Schedule of Tests

Run No.	Temperature, °K	Time, Hr	Atmosphere
1	1315	23.5	Helium
2	1297	10.0	Helium
3	1290	36.0	Helium
4	1315	21.5	Helium
5	1297	36.0	Air
6	1290	36.0	Helium
7	1315	9.0	Helium
8	1297	10.5	Helium
9	1290	10.5	Helium
10	1280	60.0	Helium

Table II. Results of Tests

Temperature, K	[illegible] Poises	[illegible] Poises	[illegible] Poises
1315	1.40×10^{10}	1.61×10^{10}	1.95×10^{10}
1297	1.68×10^{10}	1.98×10^{10}	2.48×10^{10}
1290	2.06×10^{10}	1.45×10^{10}	2.79×10^{10}
1280	2.44×10^{10}	1.69×10^{10}	3.23×10^{10}

to the activation energy for self-diffusion of 51,000 cal per mol. By more properly plotting the data, log η/T instead of log η, Alexander, Dawson, and Kling found better agreement in the value Q = 50,500 cal per mol.

The purpose of this paper is to contribute more conclusive evidence in support of the viscous creep mechanism for microcreep at high temperatures. The experimental results presented lead to a picture which gives greater correlation between viscous creep theory and experiment.

Experimental Procedure

The experimental procedure is essentially an extension and refinement of the Udin, Shaler, and Wulff[5] technique originally developed for surface tension determinations of solid metals at high temperatures. A detailed description of the technique applied to gold is given by Buttner, Udin, and Wulff.[6]

In this technique a set of 5 mil gold wires, previously marked with cut gage marks and variously loaded with gold weights, is suspended from a gold lid and surrounded by a gold enclosure in a purified helium atmosphere. While this system is heated at the desired temperature, the heavily loaded wires stretch, and the lightly loaded wires shrink due to the contractile force of surface tension. Three duplicate arrays were so heated, one for a short, one for a medium, and one for a long period of time, all at the same temperature. This was done for several temperatures between 1280° and 1315°K according to the schedule given in Table I.

The gold enclosure was held in a ceramic crucible that just fitted inside a $2\frac{7}{8}$ in. quartz tube furnace. The furnace was wound with three tapered nichrome windings, so as to give a constant temperature level over 4 in. in the middle section of the tube. Each winding was separately controlled with an individual rheostat. A thermocouple in the well of the ceramic crucible ran to a Celectray temperature controller through ports in the end plates attached to the quartz tube. The temperature was held to within ±1°F. A traveling thermocouple that could ride through a slot at the bottom of the crucible was used to maintain a temperature distribution check over the length of the furnace. The quartz tube was held in a galvanized iron box and insulated with vermiculite. A line drawing of the furnace appears in Fig. 1.

After preannealing the wires at 1200°F for a few minutes in the furnace, they were removed, straightened with tweezers, and returned to the furnace for the anneal. The normal anneal lasted for 2 hr at a temperature some 20° to 50°F above the ultimate test temperature. During this time, the wires recrystallized and the grains grew to their equilibrium size and shape. After the anneal the gage lengths of the wires were measured, and grain counts over the gage length were taken. Counts could be made easily since the grain boundary traces thermally etched out during the annealing treatment and could be seen easily. Very gently, the system was returned to the furnace for the time at temperature, removed, and the gage length again measured. The difference between the annealed gage length and the final gage length was the elongation. This divided by the annealed gage length gave the strain. The weights were removed and weighed for the determination of stress.

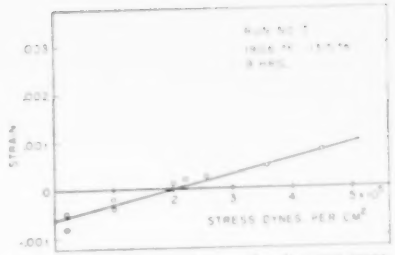


Fig. 2—Typical stress-strain curve in microcreep range with least square line.

During the time in the furnace, a purified helium atmosphere was introduced through the end plates. Purification was achieved by means of a charcoal-liquid nitrogen trap and a titanium getter in the hot zone of the furnace.

Treatment and Discussion of Data

A schedule of operations and results appear in Tables I and II. Of particular interest in this phase of the work is the slope of the stress-strain curves shown in Fig. 2. The method of least squares, assuming a straight line, was applied to the stress-strain points lying in the low stress region. From the least square calculation, stress for zero strain is found, as well as the slope of the line. The rate at which the slope increased is shown by dimensional analysis to be inversely proportional to the viscosity coefficient. The dimensions of the slope of the stress-strain curve are:

$$\frac{\text{strain}}{\text{unit stress}} = \frac{\text{strain}}{\text{dynes per sq cm}} = \frac{}{\text{sq cm}} = \text{strain per dyne} \qquad [5]$$

If these slopes are plotted for each temperature against the time of the run, as in Fig. 3, a new slope, which is the rate at which the stress-strain slope increases with time, evolves and carries the following dimensions:

$$\frac{\text{sq cm}-\text{strain}}{\text{dyne}-\text{hr}} = \frac{\text{sq cm}-\text{strain}}{\text{dyne}-\text{sec}} \times \frac{1}{3600} = \frac{1}{\eta} \qquad [6]$$

where η is the coefficient of viscosity in poises, or dyne-sec per sq cm. These slopes were found by

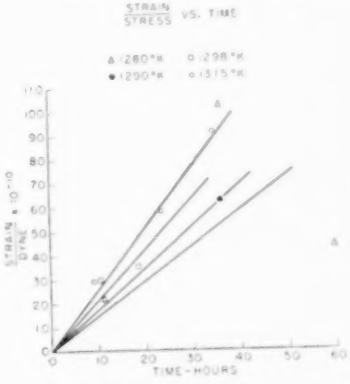


Fig. 3—Strain/stress vs. time.

Fig. 4—Experimental and calculated viscosities vs. temperature

drawing a line through the origin and the center of moments of the plotted points. The resulting experimental values of viscosity coefficients for gold plotted against temperature appear in Fig. 4. The average coefficient of viscosity for the temperature ranges used is 1.9×10^{-7} for gold.

To determine the viscosity activation energy, eq 3 was used in rearranged form. The log η plotted against $(T_m/T/TT_m)$ in Fig. 5 produced a least square slope from which a value $Q = 51{,}000$ for gold was calculated. T_m is the melting temperature as taken from the Dienes expression for D, eq 7. The origin of the quantity in parentheses is shown in Table III, where the Dienes exponential factor is brought out of Orowan's constant, C'. Bringing all the exponential factors together produces the quantity in parentheses as an exponential. It would be more proper, as Alexander, Dawson, and Kling point out, to plot log η/T instead of log T, but with the error inherent in this procedure, the present authors feel that Q values obtained are significant only in order of magnitude in comparison to the self-diffusion values of Q determined by tracer methods. Thus, it is felt justified to use an average T in the $\log \frac{kT}{C'''}$ term. However, the method shows promise if optimum test periods and weight distributions are used. Short time periods assure the strain's remaining in the linear range of the time-extension curve, but on the other hand result in low total strains. Light loads in the lower portion of the microcreep range have time-extension linearity over longer periods of time, but again result in lower total strains. Lower total measured strain results in greater uncertainty in the percentage of strain.

At 1315 K the open circle points line up well and give the most reliable slope of any. At progressively lower temperatures the slopes lie within a progressively greater range of error. Using reasonable time periods for lower temperatures, the strains measured smaller values with consequent greater uncertainty in the percentage of strain. However, the slope of a line through the origin and any point shown in Fig. 3 will produce a value for η in good agreement with the Herring prediction, considering that in the past experimental checks fall wide of the rate theory equation by factors of from 5000 to 10^7.

The only uncertain conclusion resulting from this low temperature scatter is in the final value for Q taken from Fig. 5.

In taking a straight line in Fig. 3, it is assumed that the extension-time curve is linear for all points in the microcreep range and over the full range of time periods used. Alexander, Dawson, and Kling have published data showing a good straight line relationship for gold wires on the time-extension plot over a fairly long period of time for 1 mil wire. Recent experiments of a preliminary nature in this laboratory also indicate that 5 mil gold wires under microcreep loading and equilibrium conditions tend toward a limiting strain. This agrees with Alexander, Dawson and Kling, as well as with Chalmers. However, the limiting strain occurs at about 100 hr for wires loaded in the upper microcreep range, and over 200 hr for the lower microcreep range. These are somewhat longer time periods than used in the viscosity experiments. Since the strain rate falls off before the limiting strain is reached, the upper points at 30 to 40 hr may be rather less reliable than the short time points. If in the open circle line of Fig. 3 greater weight is given to the first point, the resulting value for viscosity coefficient would be changed in the direction of better agreement with the Herring prediction for that temperature.

Theoretical Calculations of η. On the basis of Kauzman's theory, eq 1, using Dienes'[14] expression for diffusion coefficient and $Q = 51{,}000$ cal per mol, and qAl = atomic volume, the viscosity coefficient was calculated for gold and plotted in Fig. 4. The average value turns out to be 2.6×10^{-7} poises, which is roughly 10^{12} times the experimental value.

On the basis of the Herring expression, eq 2, based on the Nabarro mechanism, the viscosity coefficients were calculated for each temperature and also plotted in Fig. 4. Again Dienes expression was used to calculate the diffusion coefficients which are based

Table III. Comparison of Viscosity Equations

Orowan's Equation

$$\eta = \frac{kT}{C'''} \exp Q/RT$$

Let, $C' = C''' \exp Q/RT_m$

Then, $\eta = kT/C''' \exp \frac{Q}{R}(T_m - T/TT_m)$

$$\eta = \frac{1}{C'''}\left[kT \exp \frac{Q}{R}(T_m - T/TT_m)\right]$$

Kauzman Modified

$$\eta = \frac{\lambda L \xi T}{2qAlD}$$

Let, $D = D_0 \exp -Q/RT$ (Dienes)

Where, $D_0 = \nu = K \exp Q/RT_m$

Then, $\eta = \frac{\lambda L \xi T}{2Alq\nu K} \exp \frac{Q}{R}(T_m - T/TT_m)$

Reduce to Atomic Model, $\lambda = L = \xi$

Al = Atomic Volume = V_a

q = Unity

Then, $\eta = \frac{1}{2\nu V_a K}\left[kT \exp \frac{Q}{R}(T_m - T/TT_m)\right]$

Herring Equation

$$\eta = \frac{2\delta l RL}{3BD_{(l)}}$$

$$\eta = \frac{2Rl}{3b_{(l)}} \cdot \frac{1}{\nu K}\left[kT \exp \frac{Q}{R}(T_m - T/TT_m)\right]$$

Where, $Q_{(l)}$ = Atomic Volume = V_a

$$\eta = \frac{4Rl}{3b} \cdot \frac{1}{2\nu V_a K}\left[kT \exp \frac{Q}{R}(T_m - T/TT_m)\right]$$

on $Q = 51{,}000$ cal per mol. The other factors were $L = 1.61 \times 10^{-1}$ cm, $R = 6.57 \times 10^{-4}$ cm, and $B = 12.3$. The average calculated value is 1.36×10^{-4} poises, which agrees with the average experimental value within 28 pct.

Discussion of Results

The Herring equation has no disposable constants. Thus the order of magnitude agreement of our experiments with Herring's prediction appears quite significant. The deformation of lightly loaded wires at high temperatures is not only effectively viscous, but appears to follow the Nabarro mechanism of vacancy diffusion. The best agreement appears at 1315°K, the highest temperature used. Since the value of η was calculated from the slope of the open circle line of Fig. 3, the reliability of the 1315°K point in Fig. 4 is measured by a range of error of $\pm 0.4 \times 10^{-4}$ poises or 28 pct. There seems to be no good way of correlating the limiting strain property with the Nabarro mechanism. It may be due to changes at the grain boundary, for example, adsorption of impurity atoms, that limit their capacity to act as sinks and sources of vacancies.

It is interesting to note that here again the Kauzman equation for microcreep produces a high magnitude of deviation on the low side just as it did for Udin, Shaler, and Wulff in their data for copper. In Fig. 4 where the theoretical values are compared with experimental values, the general shape of all the curves is much the same, the only difference is in the relative vertical displacements of the curves. The shape of the curves depends on the exponential factor in the equations for viscosity, and the vertical displacement depends on the coefficients.

By rearranging the factors in all the equations used, the similarity among them can be shown and the deficiencies in Kauzman's equation can be exposed. The comparison is carried out in Table III for easy reference.

In all cases the Dienes expression for D is substituted:

$$D = D_0 \exp^{-Q/RT} \qquad [7]$$

where, $D_0 = \nu\delta^2 K \exp^{S/R}$.

In the Kauzman equation, the Dienes expression for diffusion coefficient is used, which changes the final expression into what might be termed the modified Kauzman equation. Since the Dienes expression for D is more acceptable than the early Kauzman expression, eq 1, it is the modified form that is inadvertently applied when normal D values are substituted in the normal Kauzman equation.

Comparing the Orowan equation for viscosity with Herring's equation, it may be seen that C" becomes roughly equal to the inverse of the first three factors in the latter rearranged expression. The values of these three coefficients together are higher than 1/C' by a factor of about 10. In experiments of this type, where Q is so sensitive to experimental error, this amount of discrepancy can be considered negligible because it may well arise from small errors in the exponential factor.

It will be noted that the modified Kauzman equation and the Herring equation are identical except for the two additional factors in the Herring expression. The first coefficient in Herring's rearranged equation is a function of grain size and is of the order of magnitude of 10^{-5}. Kauzman ignored the effect of grain boundaries in his analysis when he postulated an infinite continuum. The second coefficient is interesting in that it once existed in the Kauzman expression, but canceled out when the shear units were reduced to atomic size. This factor is of the order of 10^{6}. Thus together, these two coefficients are of the order of magnitude to account for the discrepancy of the order of 10^{1} indicated above in the Kauzman viscosity calculation.

The Herring equation predicts that the viscosity coefficient decreases with decreasing radius of wire. Comparing the present viscosity coefficients with those of Alexander, Dawson, and Kling, who used 1 mil wire and found a value $\eta = 1.6 \times 10^{-4}$ poises at 1000°C, it can be seen that the difference is in the right direction and approximately of the correct order or magnitude. Udin, Shaler, and Wulff reported increasing viscosity with decreasing radius, but these authors regard this as insignificant in view of the relative lack of refinement in strain measurements of these earlier experiments.

Discussion and Conclusions

In the usual treatment of creep data, it is difficult to correlate the mechanism of creep with the observed data for at least two reasons. First, the usual plots of elongation vs. time appear much the same in shape regardless of the mechanism. Second, the possible mechanisms of deformation are many, as Kauzman pointed out, and have never before been really isolated and experimentally studied individually. Some of these known possible mechanisms are viscous or slipless deformation, slip or plastic deformation, grain rotation, block or subcell movement, relative grain movement by virtue of a viscous grain boundary, and the effect on deformation of structure inversions due to phase changes or recrystallization. With all these various mechanisms, and perhaps others, operating together and all affecting one another in varying degrees depending on strain rate and temperature, it is not surprising that the resulting observations of creep are so unpredictable.

The answer may lie in Kauzman's approach of first identifying all the possible creep mechanisms and then studying each one separately, both theoretically and experimentally. Then a study of the interdependence of one mechanism on the others should follow. An example of interaction could be cited in the effect of neighboring grains to elongation in the form of grain boundary restraint. Chalmers' found that microcreep disappears in bi-

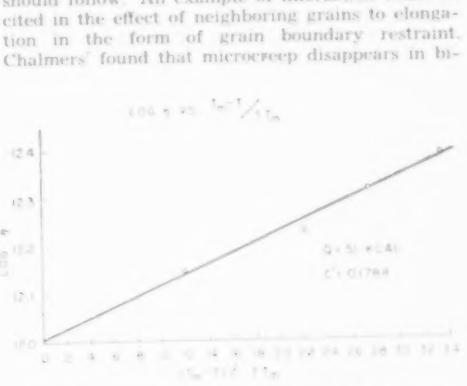


Fig 5—Log η vs. $1/T$, least square line to determine activation energy Q of viscosity.

Fig. 6—Typical stress-strain curve through microcreep and macrocreep range, showing schematic determination of macroyield point.

crystals of tin in which the grain boundary lies in the direction of pull. Rather than assume that one mechanism predominates, as is usually done, all mechanisms plus their cross effects should be considered. The difficulty lies in not being able to separate these variables.

In the present system of wires, only two deformation mechanisms appear to exist. At low stresses the Nabarro-Herring diffusion mechanism apparently acts alone. At the macroyield point, the point where the curve begins to deviate from linearity, an additional slip mechanism appears, which grows more and more active at higher stresses and is accompanied by the increased departure from linearity. This is shown in Fig. 6. These two mechanisms are probably not without their own interacting effects, however. Studies of groove angles at the traces of slip planes reveal deep groove angles that appear to be deeper the further slip proceeds.[6] This reveals slip planes to be rather high energy interfaces and can easily act as sinks in the Herring equation just as grain boundaries. Thus, the occurrence of slip reduces the average value of L and in this way lowers the viscosity.

A similar curve to Fig. 6 was determined for tin by Chalmers.[7] The linear portion he calls microcreep, the point of departure from linearity, macroyield point, and the curvilinear portion beyond, macrocreep. There appears to be no good reason why this convention cannot apply here. The wires loaded in the microcreep part of the stress range showed no visible slip lines under the 40 power telescope of the cathetometer. However, slip lines began to appear in wires just beyond the macroyield point. The amount of observable slip increases gradually in number of slip lines and amount of slip in the more heavily loaded wires. The slip occurs freely across each grain in the typical manner of single crystals. The contribution of the elongation by slip appears to add to the already operating viscous elongation mechanism.

Thus, only two mechanisms contribute to the deformation of these wires. Whether the apparent viscous mechanism acts alone or with increasing partnership with the slip mechanism depends on the strain rate. The strain rate, of course, is a function of the applied stress and temperature. There is a certain amount of grain rotation observed, as predicted by Herring, in the form of grain offsets at the grain boundaries. Since the offset movement is lateral to the direction of strain, the effect appears to be negligible on elongation. Offsetting appears only in the macrocreep range.

Subcell movement as described by Wilm and Wood[8] and others[9,10] can be fairly safely ruled out of this system. The above authors show that subcells increase in size with increasing temperature and decreasing strain rate. Since these experiments are carried out near the melting point of gold, and with the strain rates at the lowest possible, subcell size must be at a limiting maximum, which is the grain size itself.

Since there is no recrystallization, phase inversions, or grain growth during the experimental runs, and offsetting is a negligible factor, it can be concluded that at most in the macrocreep range, only two mechanisms plus a cross effect contribute to the elongation of these wires. The least operating in the microcreep range is one mechanism.

In Herring's discussion of "Calculated versus Observed Creep Rates," he raises two questions upon which these experiments throw light. The mean length of L was expected to change due to grain growth at boundaries where orientation differences are large. The fact that grain counts were sensibly the same before and after each run suggests that this effect is negligibly small in these experiments. Since an average value of L for all the wires in 10 experiments was used in the theoretical calculation, rather than estimates from a few polished specimens, this uncertainty is fairly well eliminated.

In this connection it was also suggested that grains may rotate about their longitudinal axis so as to form a low energy grain boundary. Pairs of scratches introduced on the surface on opposite sides of the wire at the start of the experiments, finally appeared as lines across and perpendicular to the grain boundaries. If axial rotation occurred, the pair of scratches would show offsets across the boundary in opposite directions. But, if the grains themselves offset laterally along a grain boundary, the pair of scratches would be offset in the same direction. Although the latter circumstance was often observed, the former was never seen to occur. Actually the grain boundary is not perfectly flat, and any curvature, steps, or discontinuities apparently offer sufficient resistance to the rotational forces to eliminate the effect.

Kinking, however, is seen to occur where two grains effectively rotate with respect to one another about an axis lying in their common grain boundary. The amount of this rotation has been found to be as high as 7° in one case, but on the average around 4°.

The question of bulging, an intermediate condition, as the wire proceeds toward an ultimate droplet state has been a topic of speculation and is discussed in detail elsewhere.[11,12]

Summary

The present study reveals that gold wires effectively creep viscously at temperatures near 1300°K

and loaded up to 4×10^7 dynes per sq cm. Between the range of 1280° to 1313° K the average viscosity coefficient was found to be 18.9×10^{14} poises, which is in good agreement with the Herring equation based on the Nabarro diffusion mechanism. The calculated average is 13.6×10^{14} poises. Herring's prediction of viscosity dependence on wire size is also supported by this work.

The creep behavior can be divided into two ranges, a microcreep and a macrocreep range, which are separated by a macroyield point according to the convention of Chalmers for the creep of tin.

The wires creep by means of two additive mechanisms in the macrocreep range after the fashion qualitatively presented by Kauzman. It is also shown that when both mechanisms occur simultaneously they affect one another.

Acknowledgment

The authors are indebted to the Office of Naval Research for funds made available under contract number N5 ori-07841 for equipment and supplies used in this research. We are also indebted to J. Wulff for his counsel.

References

[1] Kauzman: *Trans.* AIME (1941) **143**, p. 37.

[2] Eyring: *Journal of Chemical Physics* (1936) **4**, p. 283.

[3] Udin, Shaler, and Wulff: *Trans.* AIME (1949) **185**, p. 186; JOURNAL OF METALS (February 1949).

[4] Cottrell and Jaswon: *Proc.* Royal Soc., London (1949) **199A**, pp. 104-114.

[5] Nabarro: Report of a Conference on the Strength of Solids. Physical Soc., London (1948) p. 75.

[6] Herring: *Journal of Applied Physics* (May 1950) **21**, No. 5, p. 437.

[7] Chalmers: *Journal* Inst. Metals (1937) **61**, p. 103.

[8] Orowan: *Journal* West Scotland Iron and Steel Inst. (1946-1947) **54**, p. 45.

[9] Frenkel: *Journal* Phil. Mag. (1917) **33**, p. 297.

[10] Buttner, Udin, and Wulff: *Trans.* AIME (1951) **191**, p. 1209; JOURNAL OF METALS (December 1951).

[11] Funk, Udin, and Wulff: *Trans.* AIME (1951) **191**, p. 1206; JOURNAL OF METALS (December 1951).

[12] Alexander, Dawson, and Kling: *Journal of Applied Physics* (1951) **22**, p. 439.

[13] Goodwin: *Precision Measurement and Graphical Methods.* (1920) New York. McGraw-Hill Book Co.

[14] Dienes: *Journal of Applied Physics* (November 1950) **21**, No. 11.

[15] Buttner and Udin: Submitted to AIME.

[16] Chalmers: *Proc.* Royal Soc. (1936) **156A**, p. 427.

[17] Wilm and Wood: *Journal* Inst. Metals (1948-1949) **75**, p. 693.

[18] Cottrell and Aytekin: *Journal* Inst. Metals (1950) **77**, p. 389.

[19] Wood and Raschinger: *Journal* Inst. Metals (November 1949) **76**, Part 3, p. 237.

[20] Greenough and Smith: *Journal* Inst. Metals (July 1950) **77**, p. 435.

[21] Wood and Scrutton: *Journal* Inst. Metals (July 1950) **77**, p. 423.

Technical Note

Measurement of Self-Diffusion Coefficients by Autoradiography

by Harry C. Gatos and Ahmed Azzam

AUTORADIOGRAPHY would appear to be simpler and less time-consuming for diffusion studies than any of the radioactive tracer techniques commonly employed, namely, the sectioning, surface increase, and surface decrease techniques.[1] Accordingly, it was felt worthwhile to investigate the applicability of autoradiography to self-diffusion measurements, and gold was chosen for this purpose.

The radioactive isotope Au^{198} was used, as obtained from the Brookhaven National Laboratory. Its radiation consists of β (0.97 mev) and γ (0.41 mev) rays, and it has a half-life of 2.69 days. No-Screen X-ray film was found suitable for these experiments: the film has the desired high speed for recording β rays and yet is practically insensitive to γ rays. On the other hand, due to the high atomic weight of gold, this metal is a strong absorber for β rays. The

H. C. GATOS is associated with the Dept. of Metallurgy, Massachusetts Institute of Technology, Cambridge, Mass., and AHMED AZZAM with the Dept. of Chemical Engineering, Fouad 1st University, Cairo, Egypt.

TN 102E. Manuscript, Oct. 31, 1951.

This research was conducted in the Dept. of Metallurgy at M.I.T. and was sponsored by the Office of Air Research and Development under Contract No. AF33(038)-23281, Scope I.

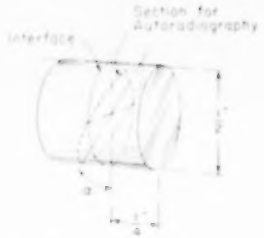


Fig. 1—Sandwich type of diffusion specimen for autoradiographic method.

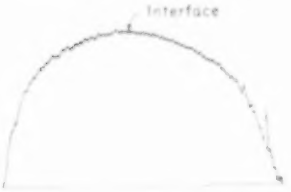


Fig. 2—Microdensitometer tracing for a specimen diffusion annealed at 1000°C for 4.77x10⁵ sec. Sectioning angle 6° 35'. Linear reduction 50 pct for reproduction.

maximum range of the 0.97 mev β rays in gold is about 0.02 cm,[2] and the most probable penetration is only about 0.006 cm.[3] Hence only the β rays emitted from a layer, comparable in thickness to that of layers commonly removed in the sectioning technique, will reach the photographic emulsion.

The diffusion specimens were of the sandwich type. A thin radioactive layer of gold (about 75A thick) was evaporated onto the one face of a gold cylinder (approximately ½ in. in diam × ¼ in. thick) in a vacuum apparatus. An identical gold cylinder was then welded to this face by hot pressing. The specimens thus prepared were diffusion-annealed for about five days, and finally sectioned across the interface as illustrated in Fig. 1. The slanted section of the remaining specimen was surface-ground and exposed directly to the photographic film. Six β-emitting sources of known relative intensities were exposed on the same film for calibration purposes. A linear relation was always found between the photographic density and the β intensity over the region of interest.

A microdensitometer tracing was obtained for each autoradiogram as shown in Fig. 2. Differences in densities between points 0.04 cm apart in the autoradiogram (about 0.004 cm apart in the specimen) could be easily distinguished by selecting a suitable amplification factor for the microdensitometer. It is evident that the highest point of the density tracing corresponds to the diffusion interface. If the diffusion specimen were sectioned symmetrically with respect to the interface, the density curve should be symmetrical. This is desirable because it affords a duplicate check within the same specimen. However, it is not always possible to obtain a symmetrical section because of the difficulty involved in locating the interface by inspection.

Data obtained for 1000°C are presented in Fig. 3, where the logarithm of the photographic density is plotted vs. the square of the corresponding diffusion distance from the interface. The actual diffusion distance was obtained from the microdensitometer tracing, taking into account the amplification factor of the densitometer and the angle α (6°35' in this case), shown in Fig. 1. The geometry involved is obvious. It is interesting to note that even though the section was not perfectly symmetrical, it was still possible to obtain checks at considerable distances on both sides of the interface.

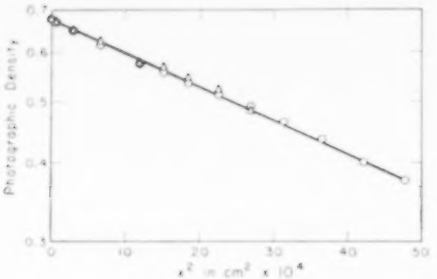


Fig. 3—Photographic density vs. square of diffusion distance. Diffusion time is 4.77x10⁵ sec. Circular and triangular points correspond to opposite sides of interface.

The self-diffusion coefficient D can be computed readily from the slope of the straight line of Fig. 3. The solution of the diffusion equation for boundary conditions at hand[4] is:

$$C = \frac{C_o}{2\sqrt{\pi Dt}} e^{-x^2/4Dt}$$

where C is the concentration of the diffusing element (photographic density in this case) at a distance x and time t, and C_o is a constant depending on the amount of radioactive gold evaporated on the surface. It follows that $\log C = \frac{-0.1086}{Dt} x^2 +$ constant. The self-diffusion coefficient of gold at 1000°C was found equal to 4.2×10^{-9} sq cm per sec. This value is in good agreement with that of 4.8×10^{-9} sq cm per sec reported by McKay.[5] With the same technique, values of D were also obtained at 800° and 900°C and found to be 1.8×10^{-10} and 1.6×10^{-9} sq cm per sec, respectively.

From these results an approximate value of 45,000 cal per mol was computed for the activation energy for self-diffusion of gold. An accurate determination of Q, however, must await the determination of D at additional temperatures.

This autoradiographic method is also being applied to the measurement of self-diffusion coefficients in alloys.

References

[1] R. E. Hoffman: Tracer and other Techniques of Diffusion Measurements. *Atom Movements*, p. 51 (1951) Cleveland, A.S.M.

[2] L. E. Glendenin and C. D. Coryell: Relation between Range and Energy of β Particles. National Nuclear Energy Series, Div. IV, Vol. 9, paper 11 (1951) New York, McGraw-Hill Book Co.

[3] R. Steffen, O. Huber, and F. Humbel: Innere Konversion der γ-Strahlung und Röntgenstrahlung beim K-Einfang schwerer Atomkerne. *Helv. Phys. Acta* (1949) **22**, p. 167.

[4] H. S. Carshaw: *Introduction to the Mathematical Theory of the Conduction of Heat in Solids*, p. 153 (1921) New York.

[5] H. A. C. McKay: The Self-Diffusion Coefficient of Gold. *Trans. Faraday Soc.* (1938) **34**, p. 845.

Origin of Porosity in Castings of Magnesium-Aluminum And Other Alloys

by E. J. Whittenberger and F. N. Rhines

The formation of casting porosity is viewed as a nucleation and growth process with solidification shrinkage and gas precipitation as cooperative driving forces. Experimental evidence evaluating the individual contribution of each force confirms the major premise that microporosity is nucleated by gas precipitation. Additional data disclose the effects of the identity and quantity of gas, the temperature range of freezing, and the freezing rate upon the amount and distribution of porosity in light metal castings.

POROSITY, as it commonly occurs in metal castings, has been ascribed to the contraction that accompanies the freezing of the metal, to the evolution of dissolved gases from the liquid during cooling and freezing, and, most frequently, to a combination of the two.[1-3] "Pipe" formation is universally associated with solidification shrinkage; spherical "gas holes" are understood to be retained bubbles of gas; but the origin of microporosity, which usually exhibits an irregular or scalloped outline when viewed in cross-section, remains a subject of continuing debate.[4-7] The present research constitutes an endeavor to show what parts are played respectively by shrinkage and gas evolution in the initiation and growth of micropores and what factors determine their number, size, shape, and distribution. A preliminary outline of the mechanism of cavity formation in castings will serve to coordinate the experimental findings that will be reported and will at the same time provide a general theory of the origin of casting porosity.

Basic to the mechanism of cavity formation that will be proposed are the following established facts: 1—that liquid metals and alloys contract gradually during cooling down to the freezing range, where a relatively large contraction, known as the "solidification shrinkage," takes place (exceptions in bismuth and gallium being noted);[1] 2—that the capacity of liquid metals and alloys for dissolving gases diminishes with cooling until, in the freezing interval, a large decrease takes place (various exceptions being noted and excluded from present consideration);[2] and 3—that freezing proceeds counter to the direction of heat flow, the freezing front most commonly being composed of a system of tapering dendrite stalks and side arms which are coarser the lower the freezing rate and which protrude into the liquid for a distance that is greater the longer the freezing temperature interval of the alloy and the smaller the thermal gradient.[8]

The mechanism by which voids are generated

E. J. WHITTENBERGER, Associate Member AIME, formerly Graduate Student, Carnegie Institute of Technology, is now Research Metallurgist, Aluminum Co. of America, Cleveland, and F. N. RHINES, Member AIME, is Aluminum Co. of America Professor of Light Metals and Member of the Staff, Metals Research Laboratory, Carnegie Institute of Technology, Pittsburgh.

Discussion on this paper, TP 3251E, may be sent, 2 copies, to AIME by June 1, 1952. Manuscript, Sept. 13, 1951. New York Meeting, February 1952.

This paper represents part of a thesis by E. J. Whittenberger submitted in partial fulfillment of the requirements for the degree of Doctor of Science to the Graduate Committee of Carnegie Institute of Technology.

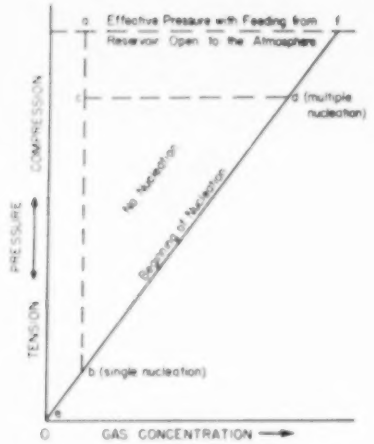


Fig. 1—Schematic representation of the cooperative effects of pressure and gas concentration upon the nucleation of a cavity.

The pressure is a summation of positive pressures such as hydrostatic head, atmospheric pressure, and surface tension and negative pressures such as the hydrostatic tension produced by the shrinkage of a confined liquid. The curve for "beginning of nucleation" is unique for each temperature value.

spontaneously during the freezing of castings may be considered as a conventional nucleation and growth process. Shrinkage and gas rejection are presumed to provide the principal driving forces of both nucleation and growth, while the pattern of the simultaneous growth of the solid phases determines the morphology of the cavities.

Nucleation

In order to initiate a void in the liquid phase, where it is assumed all casting porosity develops, it is necessary to provide a force, or combination of cooperative forces, sufficient to overcome those tending to collapse the void. The latter forces include the atmospheric pressure, the hydrostatic head of liquid metal above the site of nucleation, and the effective surface tension acting upon the void, which latter is equal to twice the surface tension of the liquid divided by the cavity radius ($2\sigma/r$).

It has been pointed out that a void cannot develop progressively from zero radius, but must spring into being at some finite size, because the surface tension factor becomes infinite at zero radius.[7] The minimum stable size is usually smaller, however, at a preexisting interface, such as the surface of contact between the liquid and solid phases.[7] Cavity nucleation occurs, therefore, predominantly upon certain types of solid surfaces, normally including such surfaces as the mold wall, floating particles of certain solid substances, or, most importantly, the surfaces of the growing solid phases.

The forces of shrinkage and gas precipitation, both of which may be expressed as pressures, are additive. Supersaturation with respect to the gas component creates an internal pressure in the liquid, which alone may overcome the collapsing forces and induce the nucleation of a gas bubble. Where the liquid is completely enclosed within impervious walls of the solid phase, its shrinkage creates a hydrostatic tension, equivalent to an internal pressure, and this alone may cause the nucleation of a void. Where a confined body of liquid contains dissolved gas, the hydrostatic tension of shrinkage and the gas pressure will cooperate to produce a cavity nucleus when their effective combined pressures exceed the collapsing force. These conditions are expressed graphically in Fig. 1, where f represents the gas content necessary to produce nucleation in a body of liquid open to the atmosphere, e represents the hydrostatic tension necessary to initiate a void in the absence of gas, and the line e-f represents the cooperative action of shrinkage and gas. This diagram is altogether schematic; the nucleation limit e-f need be straight only in the ideal case where the effective precipitation pressure is directly proportional to the gas concentration. With temperature decrease, e-f may be expected to rotate toward the pressure axis.

Consider the freezing behavior of a liquid alloy containing a small quantity of gas, a, in Fig. 1. This gas content is inadequate, by itself, to induce bubble nucleation. Suppose now that freezing has progressed until a shell of solid encloses the main body of liquid, completely isolating it from the pressure of the surrounding atmosphere. The effective pressure will drop, owing to shrinkage, and the pressure-concentration state of the liquid will fall along the line a-b. When point b, upon the nucleation line, is reached, a void will be nucleated. Its growth, i.e., increase in radius, will immediately reduce the effective surface tension ($2\sigma/r$) and the cavity will expand rapidly until the pressure acting upon the liquid has returned to some intermediate value, c, representing the combined pressure of any gas that has been rejected into the cavity plus the hydrostatic head of the liquid which will vary from one level to another, and minus, of course, the now very slight collapsing force of surface tension.

Further nucleation in this body of liquid is impossible, because the gas concentration is still too low to start a bubble under the existing pressure, and a sufficient hydrostatic tension cannot develop so long as the shrinkage is being accommodated by the growth of the existing void. As freezing progresses, however, the gas concentration in the residual liquid will increase, shifting its pressure-concentration state to the right in Fig. 1. When point d is reached, the conditions for nucleation may again be satisfied. At some site a bubble will form. This time the effective pressure upon the liquid will not be changed significantly, because this pressure is already established at an equilibrium value by the original cavity. Neither will the gas concentration of the liquid be changed in regions removed from this bubble, because composition change by diffusion requires time. Therefore, other bubbles may appear immediately at other sites.

Conditions for single and for multiple nucleation are thus defined. Where the force acting to induce nucleation is developed by an increase in hydrostatic tension, only a single nucleus can develop in any one body of liquid (single nucleation). Nucleation produced by an increase in gas concentration, however, can occur at many localities in the same body of liquid (multiple nucleation). The single nucleus tends to grow into a large cavity, called "internal pipe," which is generally recognized to be a shrinkage effect. Multiple nucleation leads to the formation of microporosity, which, as the results of the present research will show, is characteristic of gas rejection.

Single nucleation may be expected to occur where the hydrostatic head is least and where the gas is most concentrated. This is most likely to be near the

Table I. Summary of Characteristics of Porosity in Castings

Cause	Single Nucleation by Shrinkage		Multiple Nucleation by Gas		
Type	Pipe	Interdendritic	Gas hole	Intercommunicating micropore (channel type)	Isolated micropore (pinhole type)
Size	Large, often as much as half the depth of the casting.	Probably submicroscopic	Anywhere from micro size to inches in diameter.	Thinner than the isolated pore, but often as long as the casting itself.	Usually smaller than the grain size but large enough to be visible at low magnification.
Shape	Approximates that of the isotherm during freezing, with walls composed of exposed dendrite tips.	Unknown	Roughly spherical with nearly smooth surface.	Similar to the isolated pores, but connected into a continuous network by a system of thin prismatic or planar channels.	Roughly tetrahedral with surfaces composed of exposed dendrite tips.
Number	One per casting, except where the casting is of complex shape.	Probably one for every meeting of four dendrite tips in the casting, i.e., hundreds per grain.	Usually few in number.	One network may be continuous through the entire casting, or may be broken up into disconnected parts.	Depends upon gas content, ranging from none to a maximum approximately equal to the number of grains.
Distribution	Centrally located in the casting.	Uniform, probably everywhere at grain boundaries and possibly within grains as well.	Tendency to segregate toward the top of the casting.	Always at grain boundaries. Often uniform in distribution except for absence in surface skin of casting. Sometimes highly segregated, as in "spongy areas," where the volume is dictated by the requirements of shrinkage.	Always at three-grain intersections. Often uniformly distributed, sometimes highly segregated, as in "spongy areas," where the volume is dictated by the requirements of shrinkage.

top of the body of liquid, upon a solid surface, where the adjoining liquid will have the highest concentration of gas and where the surface tension forces opposing cavity formation are minimized. Multiple nucleation should occur at sites of maximum gas concentration, except where the concentration is initially so high (to the right of the nucleation curve in Fig. 1) that mere contact with a solid surface is sufficient to "trigger" the process. The maximum attainable gas concentration in a gas-poor melt is expected to lie in the unfrozen intergranular spaces of the growing solid, next to the solid face of the "mushy zone," i.e., at the ends of the liquid channels. For an intermediate initial gas content, a nucleating gas concentration may appear farther out in the mushy zone, or even near the tips of the growing dendrites. It is not expected, however, that intradendritic spaces will provide favored nucleating sites, because observation of the microstructure of complex alloys shows that the low melting constituents are rarely, if ever, so highly concentrated in the intradendritic spaces as they are at the grain boundaries, indicating that the confluence of the diffusion currents at the meeting of grains produces the highest impurity concentration. Thus, the rate of nucleation is expected to depend upon the grain size, and is higher the finer the grain size, i.e., the larger the number of intergranular spaces.

The nucleation of one pore immediately adjacent to another is very unlikely, because the gas content of the liquid must diminish rapidly in the neighborhood of a growing cavity.

Growth

Two modes of growth are to be distinguished upon the basis of whether or not liquid feeding obtains between the cavity and the exterior of the casting. 1—With feeding, the pore adjusts to the volume of its gas content under the combined pressures of the atmosphere, the hydrostatic head, and the surface tension. Its rate of growth is controlled, therefore, by the rate of gas deposition alone. 2—Where feeding from the exterior does not exist, the total volume of void space that will develop must be exactly equal to the shrinkage of the body of isolated liquid. This volume will be distributed among the cavities in such a way that the gas pressures are equalized (except for differences in head) among all cavities that are in hydrostatic communication. Thus, the average growth rate is determined by the shrinkage rate, but the growth rate for individual cavities will be modified by any differences that exist in the localized rates of gas rejection.

Growth by gas precipitation is evidently a diffusion process and, as such, its rate must depend either upon the rate of movement of gas atoms through the condensed phases, or upon their rate of passage into the vapor phase at the surface of the cavity, whichever may be the slower. Either process is complicated: 1—by the increase in cavity surface area, which, because of the complexities of pore shape, need not be related simply to the quantity of gas released, 2—by the irregularly changing ratio of gas-liquid to gas-solid interface, 3—by the flow and possible turbulence of the gas-solvent liquid as the pore grows, 4—by solubility changes accompanying temperature decrease and alloy composition change, and 5—by changes in such physical characteristics as the diffusion coefficients with alterations in temperature and composition. Hence, it is not to be expected that the rate of pore growth, by gas rejection, will follow any simple law. This, however, does not preclude certain qualitative predictions that are derivable through the identification of the nature of the process.

Growth will proceed at a declining rate until stopped by the local completion of freezing. It will never be stopped by the completion of gas precipitation, however, because, in a diffusion process, infinite time is required to attain complete equilibrium at fixed temperature. Accordingly, it is expected both that the pores will be larger the longer their period of growth and that the maximum pore volume that could be produced by the total volume of gas available for precipitation will never be attained in practice. In other words, the total volume of gas porosity should increase as the cooling rate decreases. It should be noted, in this connection, however, that gas may be rejected through the external surface of the casting during cooling and that this loss, with extremely slow cooling, may reduce, to a

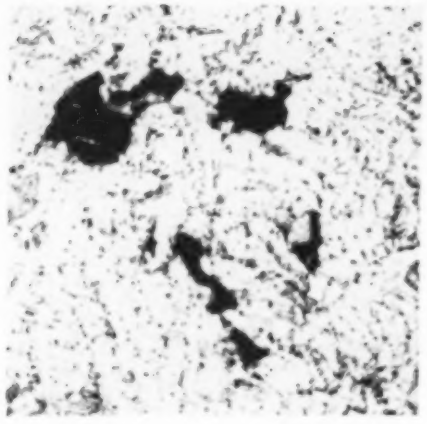


Fig. 2—Bi-Sb 90-10 alloy, chill cast, showing microporosity in a material that expands upon freezing. Nital etch. X100

significant degree, the amount of gas available for cavity growth.

The time available for growth will depend upon the rate of heat extraction from the casting and also upon the temperature interval through which the metal must cool to complete freezing. Alloys of long freezing range, accordingly, should develop a larger volume of porosity for a given initial gas content than should pure metals, or alloys of short freezing range.

Shrinkage-controlled cavity growth must proceed in direct proportion to the quantity of heat extracted from the body of confined liquid, so that its rate is predictable to the extent that the rate of heat exodus can be estimated. Where single nucleation is followed by multiple nucleation, the original single cavity has a growth advantage over the gas cavities that start their growth later. Since the relative sizes of all of the cavities that are in hydrostatic communication must be such as to equalize their internal gas pressures, the largest cavity will grow fastest, because of the larger surface area available for gas transfer. Also the original cavity is likely to be located near the geometric center of the body of liquid, where its growth can continue for the longest time and where the gas content of the liquid will reach its maximum during the freezing process.

It is for this reason that single nucleation is expected to result in the formation of one cavity that is much larger than any of its neighbors. The relative size of the neighboring pores will be the greater the earlier their nucleation, i.e., the higher the gas content of the metal. It should be noted, in this connection, however, that the size of the latter pores is not limited by their absolute gas content and that they should, in general, attain larger size than those pores growing in regions that are in hydrostatic communication with the atmosphere. Regions of gross porosity are, therefore, to be expected adjacent to internal pipe.

Where a melt contains enough gas so that multiple nucleation occurs without single nucleation, or virtually coincident with it, in a body of isolated liquid, no major cavity (pipe) will form. The microporosity in this region will equal the total volume of shrinkage and the individual pores are likely to be larger than those occurring in regions where feeding was maintained. Such accumulations of exaggerated porosity are commonly referred to as "spongy regions."

With very high gas content, the order of pore sizes may be reversed. Those growing freely in fed regions may attain a size equal to or larger than those in unfed regions, where the ultimate size is limited by shrinkage. In this case, the casting will exhibit little or no external pipe and may become "puffed."

Morphology

The principal features of the morphology of the several types of casting porosity are summarized in Table I. Some of the entries appearing in this table are not self-evident and require explanation.

There appear to be only two kinds of sites wherein the hydrostatic tension requisite to single nucleation can develop. The first is a large body of enclosed liquid and the resulting cavity is pipe. The second occurs at the very end of freezing, where four or more dendritic tips meet to enclose a minute body of liquid. Single nucleation in such a region would result in the formation of a very small, perhaps submicroscopic, cavity. Such cavities have not been reported heretofore, but indirect evidence of their existence will be offered presently.

It is very unlikely that shrinkage-induced single nucleation could occur intergranularly and thus be the source of any of the familiar microporosity. Existing knowledge of the dendritic mode of freezing indicates that the tapered dendrite arms grow in thickness upon an advancing front that bears no relation to the grain structure.[7] Hydrostatic communication among the intra- and interdendritic channels must, therefore, be maintained until the dendrite tips actually impinge upon one another at the roots of the channels. This argues against the entrapment of liquid except by small groups of dendrite tips.

Multiple nucleation, depending upon the initial gas content of the melt, may occur prior to the onset of freezing, or at any time thereafter, until freezing is completed. Gas released very early tends to form roughly spherical bubbles, which may rise to the surface and escape, or may be trapped by the advancing solid to form "gas holes." There is a regular transition in the size and shape of gas pores from the large spherical gas hole to the intergranular micropore, which may occur as an isolated cavity of scalloped (counterdendritic) outline or as a thin intergranular channel that, in the extreme, may connect with its neighbors to form a continuous void extending entirely through the casting.

The reason for the transitions among these types will be more easily perceived by reference to a simplified hypothetical example. Suppose that two bubbles are growing by gas rejection from a supersaturated liquid. One bubble, being unconfined, grows as a sphere, while the other is so constrained (as by an inverted trough) that it assumes the form of a slender cylinder. The spherical bubble will increase in diameter in proportion to the cube root of the volume of the gas added, whereas the slender cylinder will increase in length in direct proportion to the volume of gas added (assuming its diameter to remain constant). The spherical bubble will soon become enclosed in an envelope of gas-poor liquid and its growth rate will decline rapidly. The growth of the slender cylinder may continue indefinitely, however, because this bubble may advance into undepleted liquid faster than the gas diffusion path

can lengthen to slacken the supply. Thus, partial restraint of the shape of a bubble may provide it with the characteristic of sustaining growth, such as must lead to the formation of interconnecting porosity, provided that the volume of gas rejected by the liquid is sufficient.

Where gas is being released among growing dendrites, the spreading bubble may be expected to advance most rapidly along the most open channels and, for the most part, to avoid the lesser side-interstices within which the liquid would tend to be held more firmly by capillarity. The most favored site for sustaining growth, with a limited gas supply, is expected, therefore, to be along the channel formed by three adjacent dendrite systems (grains), as is commonly observed.[7] With a larger gas supply the bubble may grow also into the space between pairs of dendrite systems and farther into the intra-dendritic spaces. Meanwhile, the liquid remaining in the side interstices of the dendrite skeletons will, as it freezes, continue to reject gas into the bubble, thus contributing to the maintenance of its growth. This contribution will be the larger the greater the quantity of liquid concerned, which is to say the earlier bubble growth starts and the longer the freezing range of the alloy.

The slenderness of the gas cavity and, hence, its relative tendency to sustain growth with a given gas supply, will depend most importantly upon the depth of the freezing zone in the casting. With a deep freezing zone such as is found in alloys of long freezing range, or where the rate of heat extraction is low, long dendrite skeletons develop and the gas-rich liquid becomes concentrated in thin channels that favor the sustaining growth of channel porosity. Where the freezing range is short, or the temperature gradient very steep, the dendrites are stubby and the spaces between them more open. In the latter case, which is represented by the pure metals and certain classes of alloys, the pores tend to be isolated at the points of meeting of four or more grains.

The occurrence of interconnecting porosity open to the cast surface is usually associated with castings that exhibit surface liquation (bleeding), indicating that liquid channels have remained open to the surface until late in the freezing period and that perhaps growing gas bubbles have forced liquid out through these channels until the bubbles themselves have emerged at the surface. The existence of an association between high gas content and surface liquation has long been recognized.[7] It is apparent also, from the fact that castings may be so porous as to permit the passage of fluids entirely through them, that gas bubbles originating at different points can and do join to become one.

Constitution

The foregoing mechanism of pore formation is not specific to any one gas-metal system, or any one constitutional type, it being required only that the solubility relationships be such that gas may be rejected during cooling and/or freezing, if multiple nucleation is to occur. It is important to note, however, that the solubility relationships in any one alloy may change in a variety of ways (depending upon the constitution) as the liquid composition changes during freezing and that such changes are involved in gross as well as dendritic segregation. Thus, the tendency for micropore formation may be expected to be different from one locality to another in a casting in response to its segregation pattern. There are

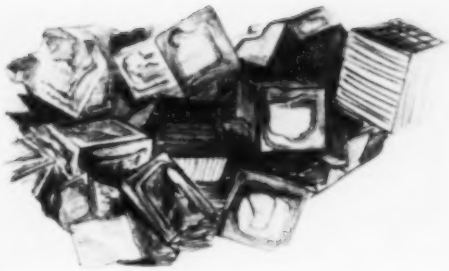


Fig. 3—Sketch of the microstructure of the inside of a pore in artificially gassed Bi-Pb (90-10) alloy, as seen in a fracture. Courtesy of R. A. Meussner. X10.

many other causes for porosity segregation, one of which has been mentioned in connection with the formation of "spongy" regions, while others are described in references that have been cited.[4-6]

Gas solubilities are usually reported in terms of volume at standard pressure and temperature. Unless this value is corrected to the temperature and pressure of gas precipitation, a gross error will result in the estimate of gas porosity. It should come as no surprise, therefore, that a substantial quantity of gas porosity can develop in a gas-metal system for which the solubility is reported to be extremely small.

Experimental Evidence

A major departure of the proposed mechanism of pore formation, from its predecessors, lies in its conclusion that microporosity depends for its nucleation (multiple nucleation), and therefore for its existence, upon the precipitation of gas. The validity of this conclusion is here demonstrated experimentally by showing, in the cases of specific materials, both that microporosity can develop in the total absence of shrinkage and that it does not develop in the total absence of gas.

Microporosity in the Absence of Shrinkage: Bismuth-rich alloys, depending upon their composition, may expand during freezing. Therefore, any microporosity that may appear in such bismuth-rich castings cannot be assigned to shrinkage and may be presumed to result from gas evolution.

A series of Bi-Sb alloys that had been melted in an open crucible in a gas-fired furnace and had been cast in an iron mold was examined. Microporosity was found in every one including an alloy of 90 pct Bi, which displays considerable expansion during freezing. The pores were of the isolated type, see Fig. 2, and were straight sided, owing to the idiomorphic outline of the bismuth-rich dendrites.

In order to show further that the straight-sided pore is characteristic of gas porosity in bismuth alloys, several cubic centimeters of air were injected into a partly frozen Bi-10 pct Pb alloy, using a hypodermic needle. The Bi-Pb alloy ordinarily exhibits little if any porosity of any kind. In this case, however, it was found to be very porous (channel type) and the exposed dendrites were idiomorphic (see Fig. 3), closely resembling in outline those seen in the normally cast Bi-Sb series.

It is worth mentioning, at this point, since the detection of porosity is a problem common to all of the experiments described in this paper, that the metallographic method is a relatively insensitive and, therefore, unreliable one for the observation of por-

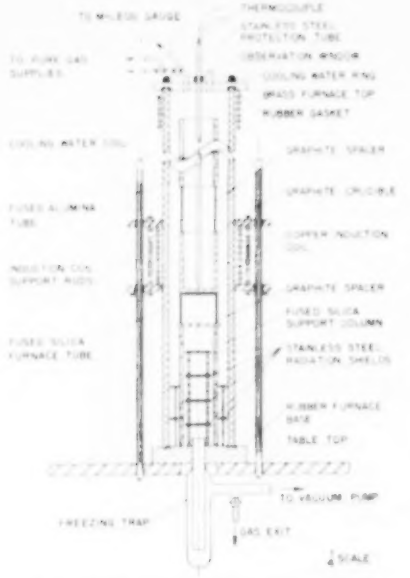


Fig. 4—Sectional view of vacuum induction furnace. Area reduced approximately 50 pct for reproduction.

unity, because the pores are often concealed by the smearing action of polishing. The most sensitive methods appear to be microradiography, the examination of the fractured surface in a sample broken at a low temperature (liquid air) to avoid smearing, and, for a quantitative measure, the density determination. In general, all of these methods have been applied in the studies here reported.

Behavior of Gas-Free Metals and Alloys: The total removal of gas from any metal is a difficult undertaking. None of the commonly practiced methods of "degassing" accomplish more than a partial removal of gas. Recourse, in the present research, was had to an adaptation of a familiar technique of the chemist, that of boiling the liquid. The more volatile fraction (the gaseous element) vaporizes preferentially. After a portion of the liquid has been boiled away, that which remains contains almost none of the gaseous element.

Most of the common metals boil at rather high temperatures, where they become chemically very reactive, so that it is difficult to maintain their purity. The boiling temperature can be lowered by reducing the atmospheric pressure, but when this is done it becomes difficult to induce the ebullient action that is so valuable in purging the liquid of gas; vaporization occurs preferentially at external surfaces. The latter disadvantage can be overcome to a large extent, however, by the use of induction heating, which provides a stirring action that continually brings fresh metal to the surface of the melt.

For the present experiments, it was necessary to construct a special boiling chamber suitable for use at very high temperatures, see Fig. 4. This consisted of a fused silica tube 4 in. in diam and 30 in. long, set vertically with metal-rubber pressure seals on top and bottom. The crucible was supported at mid-height in the tube and was thermally insulated from the ends by a series of radiation shields. The system was evacuated through the base by a high capacity oil-mechanical pump. Provision was made for introducing controlled atmospheres through a port in the furnace lid. A gas purification system was provided, also, in order to make it possible to admit to the furnace high purity gas of any kind, or mixtures of gases. Liquid air traps were made integral with the entrance and exit ports to eliminate water when this was desired. The metal was heated by an externally placed high-frequency induction coil acting variously upon the metal itself, the crucible, or a heating ring.

This equipment first was applied to the degassing of aluminum and aluminum alloys. No crucible material was found, however, which would both contain the metal at the temperature required (1700°C or higher, using a very low partial pressure of pure argon) and not contaminate it severely. Best results were had using a carbon crucible; the metal was heavily contaminated with carbon, but gas removal was effective.

For this reason, it was thought best to conduct the investigation with one of the more volatile metals. Magnesium was selected, because it has a relatively low boiling point (1105°C at 1 atm) and because typical porosity problems are encountered in its foundry applications.

Magnesium and magnesium-base alloys were readily degassed by boiling between 850° and 1105°C with anywhere from 10⁻¹ to 1 atm of pure dry argon. The apparatus was baked out under vacuum for 1 hr at 1400°C and held under vacuum overnight. The furnace was then filled with argon and the metal was introduced. Thereafter, it was re-evacuated, flushed with argon and the metal was melted and brought to the desired temperature under one-third of an atmosphere of argon. The argon pressure was reduced until boiling commenced, usually in the range of 0.004 to 0.007 atm. A major portion of the gas was evolved at this time. Then the temperature was raised while the pressure was permitted to fall until a substantial portion of the metal had boiled away. With the heating power turned off and the system still evacuated, the metal was cooled through its freezing interval at a rate of about 60°C per min.

Table II. Density of Mg-Al Alloys Boiled and Solidified in Vacuum

Composition, Wt Pct Al	Measured Density,* G per CC: As-Cast	Compressed (30,000 Psi	Annealed 1 Hr at 175°C	Published Density, G per CC ("Vosskuhler") [17]	Porosity Percentage Computed From Difference Between the "As-Cast" and "Annealed" Density	Porosity Percentage Computed From Difference Between the "As-Cast" and "Published" Density
0.01	1.7418	1.7437	1.7442	1.7440	0.040	0.034
3.00	1.7523	1.7568	1.7574	1.7557	0.290	0.199
5.29	1.7650			1.7664		0.051
5.81	1.7691	1.7870	1.7874	1.7890	0.062	0.028
8.98	1.7917	1.7940	1.7949	1.7934	0.173	0.095
12.32	1.8097			1.8085		0.424

* Maximum error ±0.0002.

Table III. Effect of 30 Min Exposure at 700° C of Degassed Mg Al Melts to Various Gases Upon Porosity of Solidified Ingots

Atmosphere*	Pct of Al	Pct of Porosity	Appearance of Porosity
Dry argon	4.82	0.096	None
Wet argon† (graphite crucible)	3.35	1.286	Channel
Wet argon† (iron crucible)	2.86	0.954	Channel
Dry hydrogen	4.58	24.44	Gas holes and channel
Wet hydrogen†	2.86	38.52	Gas holes and channel
Dry hydrogen sulphide	13.42	39.33	Gas holes and channel
Dry methane	2.43	1.552	Channel
Dry nitrogen	0.61	0.100	None
Dry nitrogen	1.47	1.833	Channel toward center
Dry nitrogen	2.01	0.501	Channel toward center
20 pct dry nitrogen; 80 pct argon	1.39	0.026	None
Dry carbon dioxide	7.50	0.603	Channel
185 mm dry carbon dioxide	3.69	0.113	Localized channel
Dry sulphur dioxide	9.58	0.997	Localized channel

* All pressures one atmosphere unless otherwise specified.
† Saturated with water at 23° C.

In every case in which a metal or alloy has been boiled in this apparatus and then solidified without exposure to a soluble gas, the resulting ingot has been altogether free from visible porosity. That is to say, no porosity has been detected by fracture, microradiographic, or metallographic examination. This statement applies to the Al-Cu alloys contaminated with carbon, to pure magnesium and to a series of magnesium-rich Mg-Al alloys. A microradiograph of a boiled sample containing 3.78 pct Al is presented in Fig. 5. This is typical of all microradiographs of the completely degassed metals. Except for a small constant discrepancy, which will be discussed presently, density measurements made upon these ingots showed the density to be that of wrought and annealed metals of like composition, see Table II.

Gas contamination of any of these metals occurs readily if they are exposed to a soluble gas subsequent to boiling and prior to freezing. When this happens, microporosity is always found. So sensitive is the tendency for gas reabsorption that microporosity has been observed to develop in a zone next to the surface of the ingot when a boiling crucible was being used for the first time, even though subjected to the above-described degassing treatment.

The conclusion seems inescapable that all microporosity, in these materials at least, is caused by the evolution of gas during freezing. It has been demonstrated both that the microporosity can develop where there is no possibility of solidification shrinkage and that none is formed when gas is absent.

Submicroscopic Porosity

Attention is now directed to the small discrepancy between the measured density of the degassed materials and the published density values for alloys of like composition. That the effect is real was shown by cold pressing (in a die) and annealing some of the cast density samples and redetermining their densities, see Table II. It should be noted that the attainment of full density was not achieved by cold pressing alone, but that a further increase to a final value was obtained by annealing after pressing. Presumably the minute pores are flattened by pressing and then "sinter" shut upon annealing.* Since the amount of deformation involved in cold pressing the samples was slight, it appears unlikely that the increase in density accompanying annealing is the same as that commonly observed after severe cold working.

This small but nearly regular difference between the densities of the as-cast and of the wrought and annealed samples suggests the presence of some kind of voids not to be associated with any such erratic variable as residual gas. Submicroscopic interdendritic shrinkage cavities previously postulated should meet the requirement of small variations in volume. The observed density differences assignable to these voids are of reasonable magnitude to be accounted for in this way.

The breadth and depth of the hypothetical interdendritic shrinkage pore in magnesium is expected to be about 2 pct of the width of a dendrite arm. This places its dimension close to or below the resolving power of the microscope (even if it were possible to polish a specimen without destroying the evidence of the existence of such a small pore). Neither do the fracture nor microradiographic methods, as now practiced, offer sufficient resolving power to detect so small a detail of structure. For the present, it is possible, therefore, to say only that there is a small residue of unfilled space in degassed cast magnesium alloys, which could be accounted for by submicroscopic interdendritic shrinkage.

Influence of Identity and Quantity of Dissolved Gas

Various gases were introduced into degassed Mg-Al alloys, by admitting the purified gases to the boiling chamber after the metal had been degassed and while it was being held molten (700° C) at reduced power input. The time of contact with the gas was always 30 min, after which the heating power was shut off and the metal was permitted to freeze. The usual fracture, microradiographic, metallographic, and density observations were made on each heat and the results are reported in Table III, with typical microradiographs shown in Figs. 6 through 9. These

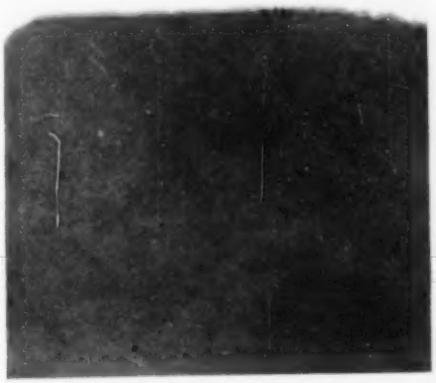


Fig. 5—Microradiograph of degassed Mg Al (3.78 pct) alloy showing absence of microporosity, which would appear as white areas if present. Vertical section taken radially from center of ingot (ragged edge). X7.

* J. L. Seaks[3] has noted a similar density increase on annealing and quenching aluminum.

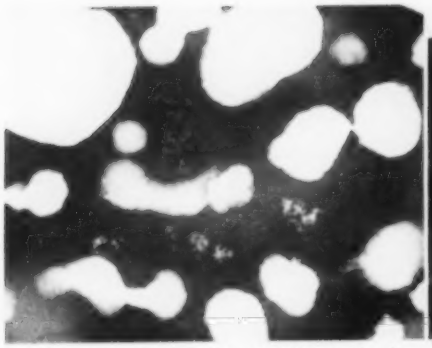


Fig. 6—Microradiograph of Mg-Al (4.38 pct) alloy degassed then exposed to an atmosphere of dry hydrogen. Large white areas are "gas holes," small white markings are microporosity. Vertical diametrical section almost across the ingot. X3

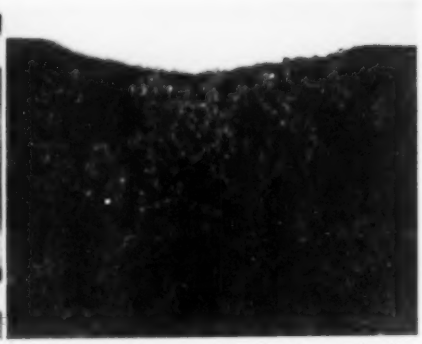


Fig. 7—Microradiograph of Mg-Al (7.5 pct) alloy degassed then exposed to 1 atm of dry carbon dioxide. White network is channel porosity that clearly outlines grains. Approximately the center one third of vertical diametrical section through the ingot. X9

Fig. 8—Microradiograph of Mg-Al (1.47 pct) alloy degassed then exposed to 1 atm of dry nitrogen. Vertical radial section, center of ingot at left, showing channel porosity in central portion of ingot. X3

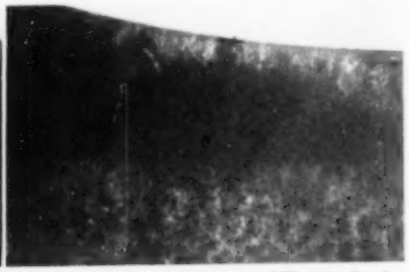


Fig. 9—Microradiograph of Mg-Al (3.78 pct) alloy degassed then exposed to 1 atm of wet argon. Vertical section showing irregular distribution of channel porosity. X9

results serve to indicate both the relative importance of the several gases in producing microporosity in Mg-Al alloys, and, in a general way, the influence of the amount of gas evolved upon the type of porosity.

In agreement with virtually all previous studies,[7] it was found here that hydrogen was foremost among the gases in producing unsoundness in magnesium and its alloys with aluminum. In contrast with some, but not all,[7] of the earlier studies, however, it was found that several other gases (nitrogen, carbon dioxide, and sulphur dioxide) were capable of producing a small, but significant, amount of microporosity.

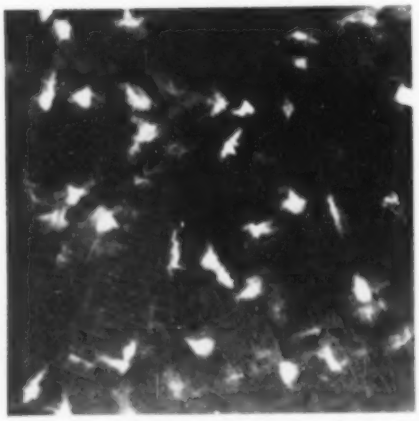


Fig. 10—Microradiograph of 17S ingot, melted in a gas muffle furnace and solidified in a graphite crucible, in air. White spots are isolated micropores, fine dark and light lines show dendrites by virtue of their varying copper content. X7

Much of the earlier evidence has tended to indicate that molecular hydrogen is not a particularly effective source of gas contamination in metals,[7] but that water vapor provides a highly active source when, upon contact with the metal, it dissociates to yield atomic hydrogen. This appears not to be the case for magnesium. Thoroughly dried tank hydrogen produced voluminous porosity. Wet hydrogen produced yet more porosity, but water vapor (0.03 atm), when carried by argon in the absence of hydrogen, had a relatively mild effect, comparable to that of nitrogen, see Table III.

Upon the basis of their dissociation pressures, the gaseous compounds of hydrogen might be expected to produce porosity in the descending order: H_2S, CH_4, and H_2O. One atmosphere of hydrogen sulphide, at 700° C, should provide the equivalent of 0.037 atm of hydrogen, methane 0.0076 atm of hydrogen and water vapor 0.000016. As anticipated, hydrogen sulphide was outstandingly the most effective in gassing magnesium, but water vapor was more efficient than methane. The latter condition is prob-

ably to be accounted for by the catalytic effect of the magnesium itself, since the metal will combine with the oxygen released by the decomposition of water, while it is relatively inert toward the carbon released by the decomposition of methane. Although hydrogen sulphide produced the largest volume of porosity of any of the gases used, it cannot be regarded as the most powerful gassing agent, since its behavior was observed in an alloy of high aluminum content which would maximize its effect; both wet and dry hydrogen appear capable of producing larger quantities of porosity.

The finding of gas porosity in the presence of dry carbon dioxide[1] and sulphur dioxide can be accounted for best by the solution of these gases in dissociated form, followed by their reassociation and rejection at the moment of freezing. The solubility

[1] Inasmuch as a carbon crucible was used, it is possible that the gas was partly or wholly converted to carbon monoxide before solution.

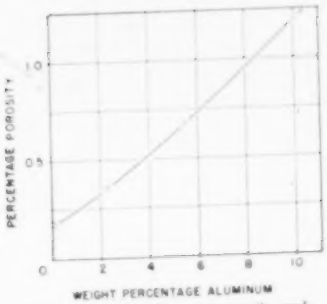


Fig. 11—Relation between porosity and aluminum content in Mg-Al alloys, degassed and then exposed to a gas mixture of argon and two volume percent of hydrogen, at 1 atm pressure. Porosity computed from density measurements.

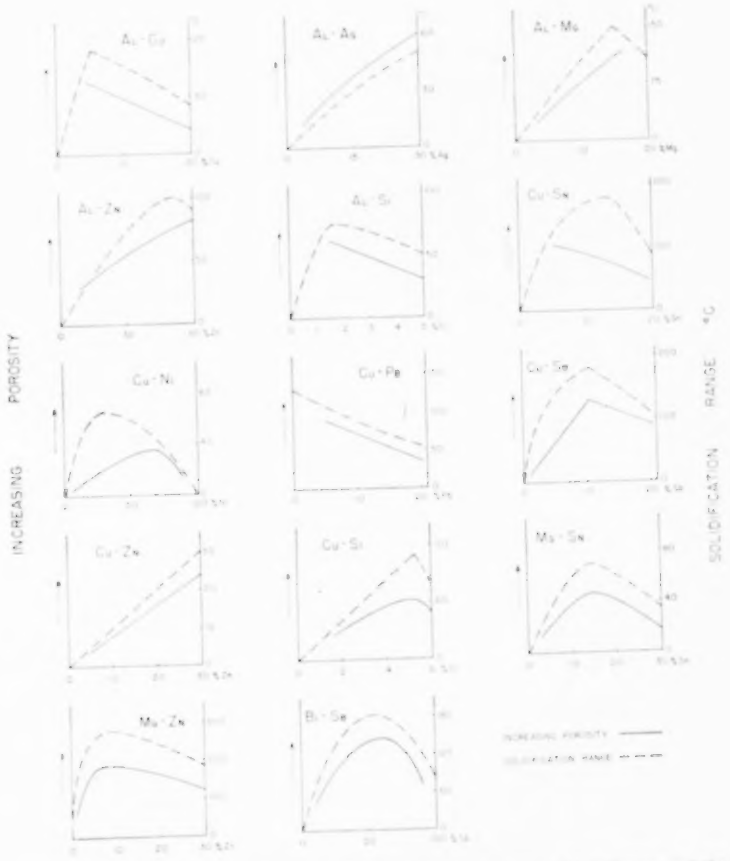


Fig. 12—Demonstration of the relationship between the temperature range of solidification and the quantity of porosity in various binary alloy series.

The quantity of porosity, estimated by metallographic means (fracture or polished section) is plotted vertically. Also plotted vertically, with the temperature scale shown in the right of each graph, is the temperature interval between the liquidus and the solidus, or the three-phase reaction line, as the case may be. Composition is plotted horizontally. It will be seen that the composition vs. porosity and composition vs. freezing range curves are generally parallel.

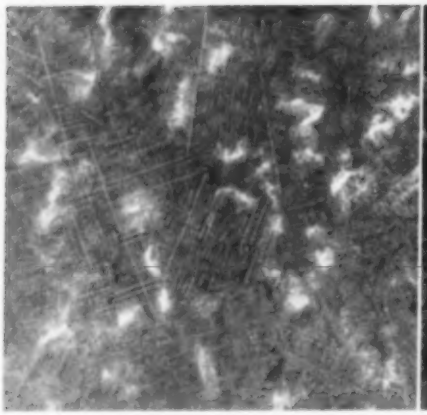


Fig. 13—Microradiograph of 175 cast in a steel mold at 600 C and cooled in air. More or less isolated micropores, tending toward channel type. X7

Fig. 14—Microradiograph of 175 cast in a steel mold and furnace cooled from 800 C. Shows long channel type pores at grain boundaries. The extent of each grain is shown by the dendrite patterns. X7

of sulphur dioxide in magnesium has been shown to be about 2 cc per 100 g of metal at 700 C,[7] but that of carbon dioxide appears to be unknown.

Where the quantity of gas released during solidification of the ingot is large, as in the cases of melts saturated with hydrogen, two varieties of gas voids appear, see Fig. 6. The large gas holes are, as expected, surrounded by rims of sound metal, giving evidence of the gas depletion of the adjacent metal. Between the gas holes, but well separated from them, there is typical channel-type microporosity. This breaking-up of the continuity of the channel porosity by gas holes may provide an explanation for the belief, sometimes held by foundrymen, that very badly gassed metal is less likely to produce leaky castings than is metal of an intermediate (critical) gas content.

Typical channel porosity, amounting to only 0.6 pct of the total volume of the casting, is to be seen in the sample saturated with carbon dioxide, Fig. 7.

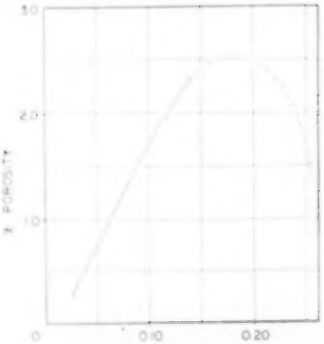


Fig. 15—Demonstration of the relationship between the freezing velocity and the quantity of porosity.

The freezing velocity is known to be inversely proportional to the dendrite spacing. The reversal of the curve with very slow cooling (large dendrite spacing) is believed to be the result of loss of gas through the external surface of the ingot.

This will serve to illustrate the continuity of porosity that can be had when its total volume is low. As a matter of fact, no isolated microporosity was found in any of the alloys of this series. A typical example of isolated microporosity may be seen in Fig. 10, which shows the structure of an aluminum-base alloy frozen in the open.

The microradiograph of Fig. 7 was compared with a micrograph of the same section, etched to reveal the grains, whereby it was found (as in many other cases) that the channel pores precisely follow the grain boundaries. Since transparencies must be superimposed to make this demonstration convincing, its reproduction here has not been attempted.

The development of centrally located "sponginess" is illustrated by the ingot that had been saturated with nitrogen, Fig. 8. Approximately one-half of a vertical diametrical section through the ingot is shown in this illustration, the center of the ingot being at the left. The freezing of the top and sides has evidently preceded the completion of freezing of the inside, at the center, and gas evolution in this region has been stimulated by shrinkage.

Reasons for irregularity in the distribution of gas porosity are not always so apparent, however, see Fig. 9. This ingot was exposed to wet argon at 700 C for 30 min. Were it not for the length of the exposure, it might be presumed that the hydrogen, absorbed from dissociated water vapor, had traveled only a short distance into the melt, prior to freezing. Under the circumstances, this appears improbable.

Influence of Temperature Range of Freezing

In order to examine the effect of the freezing range and, thereby, of the length of the dendrites upon the gas porosity, a series of heats was made in which the aluminum content of the Mg-Al alloy was varied, all other conditions being held constant. After boiling to degas the melts, they were exposed for 30 min to 1 atm pressure of argon plus 2 volume pct of hydrogen. The results of density measurements made on the solidified ingots are plotted in Fig. 11. Microradiographs of the samples showed all to contain interconnecting porosity in varying degrees. Since the solubility change of hydrogen in freezing magnesium is thought not to increase with alloying,[7] the

increase in porosity with increasing aluminum content is best accounted for by the more perfect retention of the gas bubbles and the longer time available for their growth as the freezing range increases.

Similar observations were made also upon a large group of cast alloys, including more than a hundred compositions in a variety of binary systems, see Fig. 12. These alloys had all been melted, in 1 lb heats, in a gas-fired furnace and had been cast in an iron mold, initially at room temperature.[2] They were

[2] Samples originally cast for another investigation.[8]

examined metallographically and also by fracturing at the temperature of liquid air and estimating visually the area of pores exposed. In the main, the quantity of porosity is seen to be proportional to the temperature range of freezing throughout the series.

Influence of Rate of Freezing

The influence of the freezing rate upon the quantity and distribution of gas porosity has been examined through the medium of aluminum alloy 17S ingots frozen at various rates. A large melt which had been held 1 hr at 800°C in a gas furnace containing steam was cast in rapid sequence in the following ways: 1—into a dry steel mold at room temperature, 2—into a steel mold initially at 600°C and cooled in air, Fig. 13, 3—into a steel mold initially at 800°C and cooled in air, and 4—into a steel mold initially at 800°C and furnace cooled, Fig. 14. A tightly fitting cover was placed upon each mold immediately after casting. By the use of the dendrite spacing method, developed by Alexander,[7] it was possible to make a quantitative comparison of the freezing rates of these ingots, since the dendrite spacing is inversely proportional to the freezing velocity. The dendrite spacing was then plotted as a function of the corresponding percentage of porosity, see Fig. 15.

Evidently, the quantity of porosity increases linearly with diminishing freezing velocity, up to a limit where a reversal is encountered. This behavior is consistent, in its linear range, with the proposal that the volume of gas porosity should increase in proportion to the time available for gas to be delivered to the pores by diffusion. Gas loss through the surface of the melt during furnace cooling is believed to account for the lesser porosity in the fourth sample.

The change in the character of the gas porosity from essentially isolated micropores to nearly connecting channel-type pores will be seen by a comparison of Figs. 13 and 14. In these microradiographs the dendrite skeletons of the crystals are made apparent by copper segregation, so that individual grains can be distinguished. The intergranular location of the porosity is especially apparent in Fig. 14, where the grains are so large that there is little super-position in the microradiographic sample.

Summary

Experimentally, it has been shown that:

1—Visible microporosity does not form in completely degassed Al-Cu alloys, magnesium, or Mg-Al alloys upon solidification from the melt.

2—Gases capable of producing visible porosity in magnesium and its alloys, listed in their descending order of effectiveness, are: wet hydrogen, dry hydrogen, hydrogen sulphide, water vapor, methane, dry nitrogen, dry sulphur dioxide, and dry carbon dioxide. Argon produces no visible porosity.

3—Visible microporosity forms in certain bismuth-rich alloys that expand upon freezing.

4—In visually sound castings of magnesium and its alloys, there is density evidence of an invisible (submicroscopic) porosity amounting to from a few hundredths to a few tenths of a percent, and which can be caused to disappear by working and annealing.

5—The volume of gas porosity varies inversely with the freezing velocity.

6—The volume of gas porosity increases with the temperature range of freezing of the alloys.

7—Microporosity is intergranular with only slight penetration among the dendrite arms.

Cavity formation is viewed as a nucleation and growth process with shrinkage and gas precipitation as cooperative driving forces. The principal details of the process are:

1—Single nucleation is produced by the hydrostatic tension developed by shrinkage and this nucleus according to its location grows into either an internal pipe or a type of interdendritic pore that may be submicroscopic.

2—Multiple nucleation is produced by gas precipitation giving rise to visible microporosity in all of its varieties.

3—Late nucleation occurs mainly in the intergranular channels where the highest concentration of gas is developed and microporosity is, accordingly, mainly intergranular.

4—The mode of growth is determined by whether or not liquid continuity (feeding) to the exterior of the casting obtains:

a—With feeding, the precipitation of gas controls the growth of cavities.

b—Without feeding, shrinkage determines the extent of growth, but gas precipitation determines the relative rates of growth among the cavities that are in hydrostatic communication.

5—The linear growth of gas pores may be decelerating or sustaining, depending upon the restraint imposed by the interference of the solid phases. Where the solid phases offer so little restriction that growth is essentially three-dimensional, the growth rate diminishes as the gas content of the adjacent metal declines and isolated pores are formed. If the solid phases restrict growth essentially to one dimension so that the bubble advances continually into undepleted liquid, growth is sustaining. Channel porosity results from a high degree of restraint by the solid phases.

Acknowledgment

The authors wish to express their gratitude to the Aluminum Company of America for granting to one of them a fellowship which made this work possible.

References

[1] W. A. Baker: Shrinkage and Gas Effects on the Casting of Non-Ferrous Metals and Alloys. British Non-Ferrous Metals Research Association *Series 661* (June 1944).

[2] F. Sauerwald: The Shrinkage of Metals. *Ztsch. Metallkunde* (1929) **21**, pp. 293-296.

[3] Unsoundness in Light Alloys. Report by the Subcommittee on Shrinkage and Porosity, Aluminum and Magnesium Division of the American Foundrymen's Association. *Trans.* A.F.A. (1946) **54**, pp. 563-596.

[4] H. Dobkin: Microporosity in Mg-Alloy Castings. *Foundry* (1946) **74** (10), pp. 98-101, 178, 180, 182.

[5] C. J. Smithells: *Gases and Metals.* (1937) London. Chapman and Hall Ltd.

[6] B. H. Alexander and F. N. Rhines: Dendritic Crystallization of Alloys. *Trans.* AIME (1950) **188**, pp.

1267-1273; JOURNAL OF METALS (October 1950). B. H. Alexander: The Solidification of Metals and Dendrite Formation. Doctorate Thesis, Carnegie Institute of Technology, 1948.

[7] N. P. Allen: The Effect of Pressure on the Liberation of Gases from Metals (With Special Reference to Silver and Oxygen). *Journal* Inst. Metals (1932) **49**, pp. 317-346.

[8] M. Volmer: *Kinetik der Phasenbildung*. (1939) Dresden and Leipzig: Theodor Steinkopff.

[9] A. Cibula and R. W. Rundle: The Effect of Grain Size on the Tensile Properties of High Strength Aluminum Casting Alloys. *Journal* Inst. Metals (1949) **17** (4), pp. 361-376.

[10] L. W. Eastwood: *Gas in Light Alloys*. (1946) New York: John Wiley and Sons, Inc.

[11] A. Beck: (Quoting unpublished research of Vosskühler) *The Technology of Magnesium and Its Alloys*. p. 165 (1940) London: F. A. Hughes & Co., Ltd.

[12] J. D. Edwards and T. A. Mootmann: Density of Aluminum from 20° to 1000°C. *Chemical and Metallurgical Engineering* (Jan. 12, 1921) **24** (2), pp. 61-64.

[13] J. L. Snoek: Density Variations in Aluminum. *Philosophical Magazine* (Nov. 1950) **41**, pp. 1188-1192.

[14] J. De Haven, J. A. Davis, and L. W. Eastwood: Reduction of Microporosity in Magnesium-Alloy Castings. *Trans.* A.F.A. (1945) **53**, pp. 180-189.

[15] R. S. Busk, R. F. Marande, and W. C. Newhams: Effects of Gas on the Properties of Magnesium Sand Casting Alloys. *Trans.* A.F.A. (1945) **53**, pp. 272-282.

[16] A. Schneider and U. Esch: The Solubility of Sulphur Dioxide in Liquid Magnesium. *Ztsch. Metallkunde* (1940) **32** (6), pp. 177-184.

[17] R. S. Busk and E. G. Bobalek: Hydrogen in Magnesium Alloys. *Trans.* AIME (1947) **171**, pp. 261-276; METALS TECHNOLOGY (October 1946).

Technical Note

Magnetic Behavior of Intermediate Phases in Alloys of Transition Elements

by P. A. Beck

ACCORDING to a recent hypothesis of Sully,[1] binary σ phases are characterized by 1.7 bonding 3*d* electrons per atom, which completely fill the first Brillouin zone. This hypothesis appears to imply that there are no empty 3*d* orbitals in the σ phase, and that, correspondingly, this phase must be diamagnetic, or at most weakly paramagnetic. On the other hand, Bowen and Hoar[2] reported that a σ phase extracted electrolytically from an alloy steel became ferromagnetic when cooled to about −113°C. In view of the fundamental interest of the problem from the point of view of the electron structure of the σ phase, it seemed worthwhile to study the magnetic properties of massive σ phase specimens of various known compositions.

Sigma specimens of the following compositions were tested:

1—40 atomic pct Fe, 40 atomic pct Cr, and 20 atomic pct Mo.

2—35 atomic pct Fe, 35 atomic pct Cr, and 30 atomic pct Mo.

3—48.7 atomic pct Fe, 50.2 atomic pct Cr, and 1.1 atomic pct W.

4—40.7 atomic pct Co and 59.3 atomic pct Cr.

All specimens were found to be strongly paramagnetic at room temperature, particularly alloy No. 1. At liquid nitrogen temperature, alloy No. 1 became ferromagnetic; the other σ alloys remained paramagnetic. Even though apparently not all σ alloys become ferromagnetic at liquid nitrogen temperature, in view of their strong paramagnetism it is probable that the electron structure proposed by Sully is not correct.

Similar qualitative studies were made with the μ, *P*, and δ phases.[3] A μ phase specimen of 57.2 atomic pct Co and 42.8 atomic pct Mo; a *P* specimen of 19.9 atomic pct Cr, 37.8 atomic pct Ni, and 42.3 atomic pct Mo; and a δ specimen of 50.4 atomic pct Ni and 49.6 atomic pct Mo were tested at room temperature, and all were found to be paramagnetic, although considerably weaker than the σ phase specimens described above. A test at liquid nitrogen temperature gave similar results for all specimens; none became ferromagnetic.

Thanks are due to D. K. Das for preparing several of the alloys and to Pol Duwez of California Institute of Technology for kindly loaning four specimens of σ alloys.

P. A. BECK, Member AIME, is Research Professor of Physical Metallurgy, University of Illinois, Urbana.
TN 109E. Manuscript, Jan. 25, 1952.

References

[1] A. H. Sully: The Sigma Phase in Binary Alloys of the Transition Elements. *Journal* Inst. Metals (1951) **80**, p. 173.

[2] K. W. J. Bowen and T. P. Hoar: Low Temperature Ferromagnetism of Sigma Phase in an Alloy Steel. *Research* (1950) **3**, p. 484.

[3] S. Rideout, W. D. Manly, E. L. Kamen, B. S. Lement, and P. A. Beck: Intermediate Phases in Ternary Alloy Systems of Transition Elements. *Trans.* AIME (1951) **191**, p. 872; JOURNAL OF METALS (October 1951).

Correction

In the February 1951 issue: TP 3004E, *Cobalt Self-Diffusion: A Study of the Method of Decrease in Surface Activity* by R. C. Ruder and C. E. Birchenall. P. 142: The equation for the self-diffusion in pure cobalt given in the text, the summary, and the abstract should read:

$$D = 0.032e^{-\frac{}{RT}} \text{ cm}^2 \text{ per sec}$$

where the activation energy is given as calories per gram atom.

AIME OFFICERS
President—
Vice Presidents—
President-Elect and Treasurer—
AIME STAFF
Secretary—
Ass't. Secretaries—
Ass't. Treasurer—

aime NEWS

1952 Pacific Northwest Joint Conference

Spokane, Wash., May 8 to 10, 1952

The 1952 Pacific Northwest Joint Conference—fifth annual meeting of the Industrial Minerals Div. and first meeting of the Metals Branch—will be held May 8 to 10 at the Hotel Davenport, Spokane, Wash. This conference, which was started as a one day meeting, has grown to a three day session. Sessions will be held on Extractive Metallurgy, Physical Metallurgy, Mineral Industries Education, Industrial Minerals, and Iron and Steel. F. R. Morral is Chairman of the Metals Branch meeting and R. G. Vervacke is Chairman of the Industrial Minerals meeting.

It is the desire of the conference committees to serve the mineral industry in this industrially expanding section of the country. While sponsored by AIME branches, divisions, committees, with the full support of the members, a cordial invitation is extended to all persons who have an interest in mining or metallurgy. Members of professional societies allied with these industries are welcome to benefit from the extensive program offered.

A special objective of the committee is to encourage participation of students and faculty members. To this end, arrangements are being made to provide transportation, plant trips, and other financial and educational aids for students.

The conference will end with a banquet on Saturday evening, May 10. At the dinner, James F. Bell, president, Portland Gas & Coke Co., Portland, Ore., will speak on *Quartz and Mica Mining in Brazil*.

The Spokane Chapter of WAAIME is planning a leisurely program for the ladies attending the Conference. Serving on the Local Committee for the Conference are D. L. Myers, Registration; R. O. Oscarson, Finance; W. S. Peterson, Publicity; H. P. Sherman, Hotel and Meetings; R. A. Watson, Plant Visits and Transportation; and Mrs. C. G. Sherwin, WAAIME.

It will be necessary for security reasons, that all planning to go on the plant trips register in advance.

THURSDAY, MAY 8

9:00 am

Registration

1:30 pm

Plant Visits at Mead

1—Government magnesium reduction plant, operated under contract by Pacific Northwest Alloys Corp.
2—Aluminum reduction plant of Kaiser Aluminum & Chemical Corp.

Because of security reasons, it will be necessary to preregister.

FRIDAY, MAY 9

9:00 am and 2:00 pm

Extractive Metallurgy Sessions

Chairman: A. Y. Bethune, Assistant Superintendent, Electrolytic Zinc Plant, Sullivan Mining Co., Kellogg, Idaho.

Gas Handling, Dust Collection, and Dust Treatment at Trail: Metallurgical Staff—R. R. McNaughton, Manager, Consolidated Mining & Smelting Co. of Canada, Ltd., Trail, B. C.

Bureau of Mines Electric Smelting Research Facilities and Activities at Albany: R. T. C. Rasmussen, Chief, Ferrous Metals Branch, U. S. Bureau of Mines, Albany, Ore.

Electrolytic Manganese Dioxide: W. C. Aitkenhead, Chief, Mining Experiment Station, State College of Washington, Pullman, Wash.

Operations at Garfield: R. Thompson, Superintendent, Garfield Plant, American Smelting & Refining Co., Garfield, Utah.

Converting Granulated Dross Reverberatory Speiss and Matte at Tooele: Metallurgical Staff—B. L. Sackett, Manager, International Smelting & Refining Co., Tooele, Utah.

Reverberatory Practice at McGill: Edward Pesout, Smelter Superintendent, Nevada Mines Div., Kennecott Copper Corp., McGill, Nev.

Tri-Stage Crystallization Process for Utilizing Western Ferrophosphorus: L. H. Banning, W. E. Anable and R. T. C. Rasmussen, U. S. Bureau of Mines, Albany, Ore.

Treatment of Roaster Reverberatory Flue Dust From a Copper Smelter: J. A. Finlay, Assistant Professor, University of Washington, Seattle, Wash.

Oxidation of Galena in an Aqueous Caustic Medium: J. E. Anderson, J. Halpern and C. S. Samis, University of British Columbia, Vancouver, B. C.

9:00 am

Physical Metallurgy

Chairman: Ray Ward, Head, Metallurgy Nucleonics Dept., General Electric Co., Richland, Wash.

Transformation in Co-Ni Alloys: J. B. Hess, Kaiser Aluminum & Chemical Corp., and C. S. Barrett, Institute for the Study of Metals, Chicago.

Correlation of the Band Properties of Metals: M. A. Cook, Professor, University of Utah, Salt Lake City.

Preferred Orientation and Directional Properties of 2S Aluminum: K. T. Aust and F. R. Morral, Kaiser Aluminum & Chemical Corp., Spokane, Wash.

Theory of Dendritic Growth in Metals: D. McLachlan, Professor, University of Utah, Salt Lake City.

X-ray Diffraction Techniques for Heavy Metals: J. H. Bach, General Electric Co., Richland, Wash.

1:30 pm

Plant visit to rolling mill of Kaiser Aluminum & Chemical Corp. at Trentwood.

3:30 pm

Faculty and student visit to rolling mill.

8:00 pm

Mineral Industries Education

Chairman: J. P. Spielman, Dean, State College of Washington, Pullman.

Trends in the Undergraduate Curricula: Joseph Newton, Professor, University of Idaho.

Trends in Graduate Training and Specializations: J. B. Lewis, University of Utah.

SATURDAY, MAY 10

9:00 am

Industrial Minerals

Chairman: R. G. Verrarke, U. S. Gypsum Co., Evans, Wash.

Mining Phosphate Rock: C. W. Sweetwood, Mine Superintendent, Simplot Fertilizer Co.

Vermiculite: J. B. Myers, Vice-President, Zonolite Co., Libby, Mont.

Industrial Carbon: B. W. Gamson, Director, Engineering & Research Lab., Great Lakes Carbon Corp.

Garnets: Professor McDevitt, Idaho Bureau of Mines, Moscow.

9:00 am

Physical Metallurgy

Propagation of Slip Lines in Face Centered Cubic Metals: H. Czyrewski, President, Metallurgical Engineers, Inc., Portland, Ore.

High Pressure Oxidation Rate of Metals—Copper in Oxygen: W. McKewan and W. M. Fassell, Jr., University of Utah.

Parabolic-Linear Oxidation Rate Transition Theory: W. McKewan and W. M. Fassell, Jr.

Corrosion of Aluminum: R. S. Dalrymple, General Electric Co., Richland, Wash.

11:00 am

Women's Auxiliary (WAAIME)

Brunch

2:00 pm

Iron and Steel

Chairman: J. G. Johnston, Chief Metallurgist, Bethlehem Pacific Coast Steel Corp.

Raw Materials for Steelmaking in the Western States: S. G. Sargis, Supervisor, Raw Materials, Geneva Steel Co., Salt Lake City.

Electric Furnace Melting Practices for Low and High Alloy Steels: James Gow, Chief Metallurgist, Electric Steel Foundry Co., Portland, Ore.

Production and Properties of Aluminized Steel: J. B. Russell, Kaiser Aluminum & Chemical Corp.

Adaptation of Instrumentation to Metallurgical Control Processes: L. W. Heinzinger, Metallurgical Supervisor, Bethlehem Pacific Coast Steel Corp.

Utilization of Domestic Chrome and Manganese Ores: H. A. Doerner, Chief Metallurgist, California Bureau of Mines, Region III.

2:00 pm

Industrial Minerals

Industrial Utilization of Iron Oxide: J. M. Orr, Orr Chemical & Engineering Corp., Scappoose, Ore.

Place of Coal Burning Steam Plants in the Northwest: Floyd D. Robbins, Professor, University of Washington, Seattle.

Use of Olivine in Earthenware and Semi-Porcelain Bodies: J. E. Dore, Kaiser Aluminum & Chemical Corp., P. D. Johnson, Boeing Aircraft Co., and J. I. Mueller, University of Washington.

Hot Pressing of Clay Products: Howard McDonald, University of Washington.

Evening

Banquet

Speaker: James F. Bell, President, Portland Gas & Coke Co., Portland, Ore., *Quartz and Mica Mining in Brazil*.

Board of Directors Take Up Proposed Bylaw Amendments and Changes at February Meeting

At the meeting of the Board of Directors, AIME, on February 17, the Directors signified their intention of amending Art. VII, Sec. 3, paragraph 3, as follows:

Present wording: "The funds of the Institute shall be paid out by checks signed by the Treasurer and countersigned by the Secretary; in case of absence or disability, the President or any Vice-President may act for the Treasurer, or any Vice-President for the Secretary, but the Treasurer may, at his discretion, place funds of the Institute, not at any time exceeding $2,000, at the disposal of the Secretary's office for the purpose of paying the smaller current expenses of the Institute and may also establish a payroll account. Such funds shall be banked in the name of the Institute and drawn by checks signed by any two of the following persons: Secretary, Assistant Secretary, Assistant Treasurer, or Office Manager."

To be revised to read: "The funds of the Institute shall be paid out by checks signed by the Treasurer and countersigned by the Secretary. The Treasurer or Secretary may at any time appoint any officer or employee of the Institute to act for him. In case of absence or disability, the President, any Vice-President, Assistant Treasurer, Assistant Secretary, or Controller may act for the Treasurer and/or the Secretary. The Treasurer may at any time place funds of the Institute not exceeding $10,000 at the disposal of the Secretary's office for the purpose of paying the current expenses of the Institute and may also establish a payroll account. Such funds shall be banked in the name of the Institute and drawn by checks signed by any two of the following persons: Secretary, Assistant Secretary, Assistant Treasurer, Controller, Business Manager, Office Manager."

Notice of intention to amend Art. VIII, Sec. 2, paragraph 3, was also given.

Present wording of 6th, 7th, and 8th sentences: "All bills, accounts, salaries, payrolls, and claims of every kind against the Institute shall be examined by the Finance Committee and be approved by at least one member of the Committee. The Committee shall not authorize any payments in excess of appropriations. If at any time any of the appropriations seem in danger of being insufficient, the Finance Committee shall report the same to the Directors."

To be revised to read: "All bills, salaries, accounts, payrolls, and claims of any kind against the Institute within the approved budget of the year shall be examined and approved by the Secretary or such officer or employee of the Institute whom he may designate. Any such payments not included in the approved budget shall be examined by the Finance Committee and signed by at least one member of the Committee. The Committee shall not authorize any payments in excess of appropriations. If at any time any of the appropriations seem in danger of being insufficient, the Committee shall so report to the Directors."

The above suggested changes will be acted upon by the Board at its meeting on April 16.

Membership Endorsement

To ease the transition from Student Associate to Junior Member, the Board of Directors, at its meeting on February 17, proposed that the bylaws be changed to reduce to one the number of endorsers needed by graduating students in applying for the higher status. The Student Associate would be sent an application blank immediately on leaving school. This

would be endorsed by one member, but not the same member who originally endorsed him for Student Associateship. The Admissions Committee would act upon this application and if their recommendation was favorable the Board would elect the applicant to Junior Membership at the end of the year, when his Student Associateship would expire. He would then be billed for the succeeding year's dues as a Junior Member. To permit this change in procedure, the Board will vote, at its April 16 meeting, on the following change in the pertinent bylaw, Art. I, Sec. 9, first sentence.

Present wording: "Every candidate for election as a Member, Junior Member, or Associate Member must be proposed for election by at least three Members, Junior Members, or Associate Members, must be approved by the Committee on Admissions, and must be elected by the Board of Directors, and not less than three fourths of the votes cast shall be necessary to election."

To be revised to read: "Every candidate for election as a Member, Junior Member, or Associate Member must be proposed for election by at least three Members, Junior Members, or Associate Members, provided, however, that in the case of a Student Associate applying for Junior Membership only one proposer in addition to the member who nominated him for Student Associateship be required. All candidates for election to membership must be approved by the Committee on Admissions" . . . etc as above.

Proration of Dues

A proposal emanating from the Council of Section Delegates in 1951, that dues of new members be prorated according to the number of months remaining in the calendar year following the date of election, was favorably regarded by the Directors at their February 17 meeting. They recommended a change in the bylaws to make this effective. It is therefore proposed to change Art. II, Sec. 2, 3d sentence as follows:

Present wording: "Members, Junior Members, or Associate Members elected on or after June first of any year shall pay, on receipt of Treasurer's statement, one half of said amount for the year of election, and if elected in the month of October, November, or December, the candidate may defer acceptance to the first of the following year without loss of status."

To be revised to read: "Newly elected Members, Associate Members, or Junior Members shall, on receipt of Treasurer's statement, pay the current year's dues on a pro rata basis for the number of months remaining in the calendar year following the month of election."

It is expected that the amendment will be voted on at the meeting of the Board on April 16.

IMD Fall Meeting Paper Deadline

Apr. 15, 1952 is the deadline for all Institute of Metals Div. papers to be presented at the fall meeting, Oct. 20 to 22, at the Hotel Adelphia, Philadelphia.

Increase Representation

A proposal originating last year with the Mining and Metals Branch Councils, that Branch Council Chairmen be ex-officio members of the AIME Board of Directors was regarded favorably by the Board at its meeting on February 17. This had been advocated also by a special Committee on increased divisional representation on the Board, John R. Suman, chairman. This committee had also recommended three-year terms for Divisional representatives, instead of the present one-year term for Divisional Chairmen, but the Board took no action on this part of the Committee's recommendation.

To effect the proposed change, the Directors, at their meeting on April 16, will vote on the following change in Art. VI, Sec. 1:

Add the words in italics: "The number of Directors of this Corporation is 27, consisting of one President-elect, one Past President, six Vice-Presidents, and 18 other Directors, to be elected as hereinafter provided; and in addition the Chairman of each duly constituted professional Division *and of each Branch Council* of the Institute, ex officio, shall serve as a Director, with full voting power, during his term as Chairman, *provided, however, that such ex-officio Directors shall have but one vote if they are already duly elected members of the Board.*

"At the regular November meeting of the Board of Directors or Executive Committee, the chairman therefore shall declare to be elected, as provided in Art. IX of these Bylaws, nine Directors, of whom one shall also be designated as President-elect, and of whom two shall be designated as Vice-President. The nine Directors, including the Directors designated as officers, together with the newly elected Division *and Branch Council* Chairman in their capacity as ex-officio Directors, shall take office at the annual business meeting of the Institute next following the meeting at which they were declared elected . . . ."

Future Dues

Perhaps the most important item on the agenda for the Board of Directors' meeting on February 17 was that of what the policy should be on future dues. Until 1950 the AIME dues were $15 for Members and Associate Members and $10 for Junior Members for the first six years of such membership, thereafter $15. As recommended by the Section Delegates at their meeting in San Francisco in 1949, and as subsequently confirmed by a vote of 78 pct of the voting membership, these dues were raised by $5 for Members and Associate Members and by $2 for Junior Members for the years 1950, '51, and '52 only. In 1953 the dues go back to the former level unless the Directors and the membership, through a referendum, vote otherwise.

The deficit for 1949 was $72,048. With the higher dues schedule, the deficit in 1950 dropped to $14,854. This last year, 1951, in spite of increased costs, a surplus of $8009 was achieved. Two principal factors in the improvement were increased advertising income from the journals, and the fact that no Directory was published in 1951. The preliminary budget for 1952 shows a surplus of $6000.

In studying the probabilities for 1953, several factors must be considered. Enrollment of new members should result in an increase in the dues income, and advertising income will also likely increase, as it has done each year since 1949 when the new journals were established. On the other hand, if the value of the dollar continues to decline, unit costs of what the Institute buys will increase. (Based on 100c for the 1935-39 dollar, the dollar at the end of 1949 was worth 60c; 1950, 56c; and 1951, 53c.) Further, during the eight years of deficits the Institute's reserve Funds were tapped by an amount exceeding $200,000, bringing those available to meet such deficits virtually to the vanishing point. Prudence would indicate that some restitution should be made to these reserve Funds to take care of possible future requirements. Such restitution must be made from surpluses over the next few years.

Data were presented at the Board meeting indicating that, based on billings for 1952 dues, income from dues payments would be reduced by approximately $69,000 if the dues went back to the pre-1950 level. This would undoubtedly force a radical cut in the services performed, and a reduction in the quantity of published material, with a quite possible resultant reduction in advertising income as well. There was considerable discussion of a proposal from the Petroleum Branch that separate dues be established for each Branch, consistent with providing sufficient income to meet Branch expenses, and allowing a sufficient surplus to pay back the amount taken from reserve funds over a ten-year period. The final vote, with but two or three Directors dissenting, was that an amendment to the bylaws continuing the present dues schedules for all classes of membership be submitted to the member-

ship for a referendum. A statement will be included with the ballot, and published in the journals, as to why it is believed continuance of the present dues schedule is believed to be for the best interest of AIME members.

Arrears Canceled

Hereafter, Student Associates and Junior Members who have been dropped from the AIME rolls because of arrears in dues will have such arrears canceled if they are obligated to pay an initiation fee. If such persons have passed their 30th birthday they must be reinstated as Associate Members or Members and are thus liable for the $20 initiation fee, though it may be paid in $5 annual installments. The Board, which took the above action at its meeting on February 17, felt that a charge for arrears in dues in addition to the initiation fee and current dues was too much of a hardship. Reinstatement of other members who had heretofore paid an initiation fee is made without any charge except for current dues unless they were in arrears for dues when their membership terminated, in which case the arrears must be paid, but not in excess of $20.

1953 Awards Authorized

Income in the AIME Award Funds being sufficient, the Board has authorized the committees administering the respective awards in the following list to proceed to the selection of candidates or projects: *Charles F. Rand Memorial Medal* for distinguished achievement in mining administration (or income from the Fund may be used for other purposes); *Robert W. Hunt Award* for the best paper on iron and steel; *J. E. Johnson, Jr. Award* for distinguished achievement in the metallurgy or manufacture of pig iron, by a man under forty years of age; *Rossiter W. Raymond Award* for the best published paper by a member under 33 years of age; *Mathewson Gold Medal* for a paper or papers considered the most notable contribution to metallurgical science in the field of the Institute of Metals Div; *Robert H. Richards Award* for achievement in the art of mineral beneficiation. The Secretary of the Institute will be glad to forward to the respective committee chairmen any suggestions or nominations with regard to the above honors.

Session Chairmen Named For New England Regional Conference

Technical session chairmen have been named for the Sixth Annual meeting of the New England Regional Conference of the Institute of Metals Div., AIME, April 25 and 26 at the Hotel Kenmore, Boston.

D. K. Crampton, director of research, Chase Brass & Copper Co., and P. R. Kosting, Watertown Arsenal, will act as associate chairmen for the first session, Friday, April 25, at 2:00 pm. A. J. Pepin, assistant to the president, Wyman-Gordon Co., will be chairman of the Saturday session, starting at 9:30 am.

A banquet is scheduled for Friday Evening, with E. A. Anderson, chief, Metal Section, Research Div., New Jersey Zinc Co., in the roll of toastmaster. Fred L. Whipple, chairman, Dept. of Astronomy, Harvard University, will be the speaker. He plans to consider the technical problems of rocket design and the astronomical and medical hazards of interplanetary travel. Mr. Whipple already noted the problems which may occur once the Earth's gravitational pull no longer has any effect upon the weight of space travelers.

Delegates to the conference will visit the New England Metallurgical Corp. plant in Boston Friday morning. Various commercial heat treating operations are to be studied.

1955 Annual Meeting To Be Held In Chicago

An invitation to hold the Annual Meeting in Chicago in 1955 has been accepted by the Board of Directors. Unless otherwise determined by the Board, the dates will be Feb. 14 to 17. Chicago will also be the scene of the fall meeting of the Institute this year, on Sept. 5 to 6, in connection with the Centennial of Engineering celebration.

Philadelphia Section Hears Talk On Corrosion

At the Feb. 14, 1952 meeting of the Philadelphia section, AIME, Dr. Hoxeng, chemical metallurgist of U. S. Steel Laboratories, Pittsburgh, presented a lecture to 35 AIME members on the *Physical Chemistry of Corrosion*. He outlined the principal kinds of corrosion, and showed by sample calculations how thermodynamics was useful in predicting corrosion susceptibility but not rate. The use of polarization curves to express corrosion velocity was also demonstrated. Finally the various methods for protection of metals were reviewed and their principles explained in detail. A discussion of practical corrosion problems in light of the concepts presented in the lecture followed.

Coming Events

Mar. 31-Apr. 2. AIME, annual conference, Blast Furnace, Coke Oven, Raw Materials Committee and Open Hearth Steel Committee, William Penn Hotel, Pittsburgh.

Apr. 1. Society for Applied Spectroscopy, Society Vacuum Training Center, 60 Park Row, New York.

Apr. 1-3. American Society of Lubrication Engineers, annual meeting, Statler Hotel, Cleveland.

Apr. 1-3. American Management Assn., spring manufacturing conference, Hotel Statler, New York.

Apr. 3. AIME, Chicago Section, Chicago Bar Assn., Chicago.

Apr. 3-11. Society of Plastics Industry, reinforced plastics div., Chicago.

Apr. 11-12. AIME, South West district, Jefferson Hotel, St. Louis.

Apr. 12. AIME, Philadelphia, Engineering Bldg., University of Pennsylvania, Philadelphia.

Apr. 21. AIME, Chicago Section, National Open Hearth Steel Committee, Phil Sindt & Sons, Whiting, Ind.

Apr. 21-22. American Zinc Institute, annual meeting, Hotel Statler, St. Louis.

Apr. 21-25. SAE, national aeronautical meeting, New York.

Apr. 22. Assn. of Consulting Chemists & Chemical Engineers, Inc., general symposium, Hotel Belmont Plaza, New York.

Apr. 23-26. AIME, New England Regional Conference, Kenmore Hotel, Boston.

Apr. 26-May 11. Liege International Fair, Liege, Belgium.

Apr. 29-30. Metal Powder Assn., annual meeting and exhibit, Drake Hotel, Chicago.

May 1-2. American Foundrymen's Society, International Foundry Congress and Show, Convention Hall, Atlantic City, N. J.

May 1-3. Electrochemical Society, Inc., spring meeting, Benjamin Franklin Hotel, Philadelphia.

May 5-6. National Air Pollution Symposium, Huntington Hotel, Pasadena, Calif.

May 6-9. Scientific Apparatus Makers' Assn., annual meeting, Edgewater Beach Hotel, Chicago.

May 9-10. AIME, joint meeting, Industrial Minerals Div., and Metals Branch, Davenport Hotel, Spokane, Wash.

May 11-14. American Institute of Chemical Engineers, Atlanta Biltmore, Atlanta.

May 22-24. American Society for Quality Control, annual convention, Onondaga County War Memorial, Syracuse, N. Y.

June 16-20. Industrial Finishing Exposition, International Amphitheatre, Chicago.

June 23-27. ASTM, 50th anniversary meeting, Hotel Statler, New York.

July 1-Sept. 30. Centennial of Engineering, Chicago.

Aug. 25-29. Oak Ridge Summer Symposium, Oak Ridge, Tenn.

Sept. 1-13. AIME, Chicago Section, Centennial of Engineering, Chicago.

Sept. 22-25. American Mining Congress, Metal and Nonmetallic Mining Convention and Exposition, public auditorium, Denver.

Sept. 23-25. Institution of Mining and Metallurgy, symposium on mineral dressing, Royal School of Mines, London.

Oct. 3. AIME, Southern Ohio Section, National Open Hearth Steel Committee, Deshler-Wallick Hotel, Columbus, Ohio.

Oct. 10. AIME, Eastern Section, National Open Hearth Steel Committee, Warwick Hotel, Philadelphia.

Oct. 10. AIME, Southwestern Section, National Open Hearth Steel Committee, Pevely, Ill.

Oct. 20-22. AIME, Institute of Metals Div. fall meeting with National Metal Congress, Hotel Adelphia, Philadelphia.

Oct. 22-24. Porcelain Enamel Institute, Greenbrier Hotel, White Sulphur Springs, W. Va.

Oct. 28. Assn. of Consulting Chemists & Chemical Engineers, Inc., annual symposium, Hotel Belmont Plaza, New York.

Nov. 7. AIME, Pittsburgh Section, National Open Hearth Steel Committee, Hotel William Penn, Pittsburgh.

Dec. 1-6. AIME, Electric Furnace Steel Conference, Hotel William Penn, Pittsburgh.

Feb. 16-19, 1953. AIME, annual meeting, Statler Hotel, Los Angeles.

Apr. 20-22. AIME, National Open Hearth and Blast Furnace, Coke Oven and Raw Materials Conference, Hotel Statler, Buffalo.

AIME Financial Analysis For 1951 Shows Operating Surplus of $8000, First In 9 Years

Membership at the end of the year 1951 was 19,711 including 2228 Student Associates. The data in the third column include these Student Associates.

1. This includes all the cash dues income received from new and old members of all grades.
2. All cash initiation fees received.
3. Net income received from advertising in the three journals. The figure was $72,273 for MINING ENGINEERING; $39,844 for the JOURNAL OF METALS; and $31,564 for the JOURNAL OF PETROLEUM TECHNOLOGY. Income in 1950 was $54,572, $30,390, and $18,443 from these sources, respectively.
4. Receipts from individual sales, nonmember subscriptions, and multiple subscriptions of members.
5. Includes Transactions volumes and the Petroleum Statistics volume.
6. Sales of all other printed matter except special volumes sponsored by certain Funds. Includes a considerable sale of preprints and reprints of technical papers.
7. Does not include dividends and interest from certain Funds whose income reverts to those Funds.
8. Miscellaneous income not included in any of the above categories.
9. The total income compares with $493,197 in 1950, an increase of $29,000.
10. Consists principally of appropriations made to Local Sections (about $10,000), traveling expenses of delegates to the Annual Meeting, and $866 refunded to Local Sections as representing 10 pct of the initiation fees paid by members in their respective Local Section territories.
11. Includes all appropriations made to divisions and branches and salaries and expenses of paid division and branch officers; also rental for offices used for divisional or branch purposes.
12. All expenses of the AIME Secretary in New York and in the field.
13. Net cost of Annual and mid-year meetings and such other meeting expense as not properly chargeable to branches, divisions, or Local Sections or borne by them. Profits or losses on social functions at all-Institute meetings are for the account of the host Local Section.
14. Net AIME contribution to the support of the Engineering Societies Library. A further contribution to the Library came from interest on the James Douglas Library Fund of $106,000.
15. AIME headquarters occupies 7157 sq ft in the Engineering Societies Building in New York and contributed about $2.40 per ft per year for building maintenance. A small part of this is charged in item 11 for Mining and Metals Branch office space, the rest appears here.
16. Includes the salaries and expenses of the editorial and advertising staffs; paper, printing, and distribution. Net cost can be obtained by subtracting items 3 and 4 from this total.
17. Printing, paper, binding, and distribution of Transactions and Petroleum Statistics volumes.
18. Compiling, printing, and distributing the 40-page directory of officers, committee personnel, Local Sections, Student Chapters, etc, distributed with the journals last spring.
19. Costs of reprints and other miscellaneous publications not otherwise mentioned, or paid for by specific Funds.
20. Salaries and expenses of members of the New York staff not primarily concerned with publications, accounting, or membership; telephone, telegraph, general postage, stationery, and other supplies.
21. Salaries and all expenses in the accounting dept. at New York.
22. Salaries and all expenses connected with approaching prospects for membership, processing applications, and recording changes of address and title.
23. Cost of noncontributory insurance and annuity policies for AIME employes of more than five years' service. Income from canceled policies redounds to the Pension Fund so this item may vary greatly from year to year.
24. Various types of insurance carried by the Institute.
25. Maintenance of furniture and equipment.
26. Larger than usual because of purchase of new equipment and scrapping old; disposal of unsalable volumes; and adjustments for past years.
27. Reserve set up for probable loss on delinquent accounts.
28. Expense that does not fit into any of the above classifications.
29. Compares with expense of $508,051 in 1950, an increase of $6016.

It should be noted that the Member and Associate Member paying $20 dues is subsidizing completely the Senior Members (members of at least 30 years' standing and over 70 years old who apply for this grade) and Honorary Members, neither of whom pay any dues but receive all privileges. They also subsidize in part Junior Members, most of whom pay $12; and to a large extent they subsidize Student Associates, who pay $4.50.

INCOME AND EXPENSE STATEMENT, 1951

Income

		Total Amount	Pct of Income	Amount per Member
1.	Dues	$293,348	56.5	$14.90
2.	Initiation	11,054	2.1	0.56
3.	Advertising	143,681	27.5	7.29
4.	Sales journals	22,902	4.4	1.16
5.	Sales annual volumes	22,142	4.2	1.12
6.	Sales other publications	15,864	3.0	0.80
7.	Dividends and interest	4,203	0.8	0.21
8.	Miscellaneous	6,802	1.3	0.35
9.	Totals	$522,076	99.8	$26.47

Expenses

			Pct of Expense	
10.	Local Sections	$14,280	2.8	$0.72
11.	Divisions and Branches	54,011	10.5	2.74
12.	Secretary's expense	2,116	0.4	0.11
13.	Meetings	4,168	0.8	0.21
14.	Library	6,522	1.3	0.33
15.	Building rental	13,035	2.5	0.66
16.	Journals	248,066	48.4	12.58
17.	Annual volumes	36,195	7.0	1.83
18.	Directory	2,194	0.4	0.11
19.	Other publications	7,561	1.5	0.38
20.	General and administrative	46,574	9.1	2.36
21.	Accounting	25,568	5.0	1.29
22.	Membership	22,945	4.5	1.16
23.	Pension	4,397	0.9	0.22
24.	Insurance	505	0.1	0.03
25.	Furniture and fixtures	1,454	0.3	0.07
26.	Depreciation of equipment	12,500	2.4	0.63
27.	Delinquent accounts	3,000	0.6	0.15
28.	Miscellaneous	8,966	1.7	0.45
29.	Totals	$514,087	100.2	$26.01

Photographs Courtesy International Nickel Co.

Metals Branch Holds 35 Sessions at AIME Annual Meeting

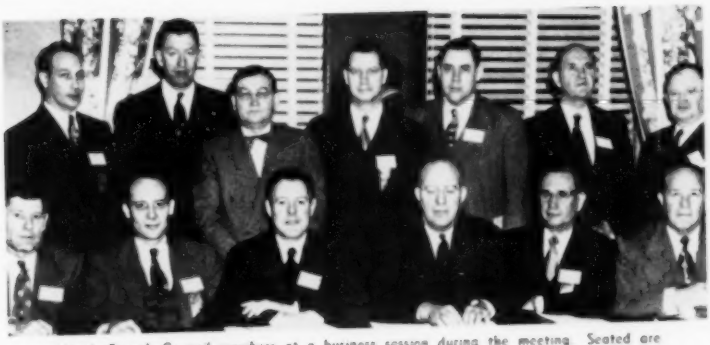
Record Number of Registrants Hear Wide Variety of Papers

APPROXIMATELY 3500 people thronged the Hotel Statler from February 18 to 24 for the 173rd general meeting of AIME. It was a technical extravaganza in that 82 technical sessions were held, at which 300 authors presented some 350 papers. Fortunately, Jerry Peirce, outgoing President, didn't have to preside at all the events although after his year's stint as President, he has more than a nodding acquaintance with some of the latest problems in the mining, metals, and petroleum industries.

Although the Welcoming Luncheon on Monday noon was the official opening of the meeting, Local Section Delegates and the Board of Directors convened on Saturday and Sunday, respectively. The large attendance and business like demeanor of these two groups was in accord with the energetic and competent service they have rendered the Institute through the year. To the applause of engineers and their wives who thronged the grand ballroom of the Statler for the Welcoming Luncheon, President Peirce introduced Oliver B. Hopkins, president of the Canadian Institute of Mining and Metallurgy and C. Gerow, secretary of CIM. Dr. Hopkins brought greetings from the CIM and expressed his satisfaction in the splendid spirit of cooperation that exists between the two Institutes. Dr. Hopkins is president, Interprovincial Pipe Line Co., Toronto, and counts as a close personal friend M. L. Haider, who is the 1952 President of AIME and lately of Toronto where he was a director and general manager of Imperial Oil Ltd. Mr. Haider will be known shortly as Mike to thousands of AIME members as he makes his presidential tour of the Local Sections.

There was a pause in luncheon proceedings when Judge Harold R. Medina arrived amid the applause of the audience and somewhat breathless from his trip via motorcade from an antitrust trial against investment bankers at the courthouse downtown. With the Judge at his elbow, President Peirce took the opportunity in his introduction to good humoredly chide the Judge for the vixenish habits of public servants in their treatment of astute businessmen. The successful inventor who

W. McG. PEIRCE, left, who turned over the reins of AIME to 1952 President M. L. HAIDER, right



Metals Branch Council members at a business session during the meeting. Seated are R. M. Parke, R. M. Brick, C. C. Long, H. K. Work, T. L. Joseph, and K. C. McCutcheon. Standees include E. O. Kirkendall, Evan Just, M. Gensamer, W. A. Dean, D. S. Eppelsheimer, O. C. Ralston, and T. D. Jones.

patents his inventions is a monopoly; the copper manufacturer who buys his competitors a drink is in collusion; but the business failure need only look to the government for a subsidy, Mr. Peirce pointed out.

Judge Medina quickly captured the admiration of his listeners. He spoke about justice, deploring partisan deals on nominations for judgeships. With his simple phrases and stirring anecdotes he made his point but, more than that he renewed the confidence of the people in the integrity of the judiciary.

Four prizes of $100 each were awarded to the winners of the Tenth National Student Prize Paper Contest, at this luncheon. These went to John F. Radavich for his paper *A New Electrolytic Stripping Technique*; Charles R. Rainesalo for his paper the *Tensile Properties of An Aged 31 Pct Cr-Fe Alloy*. Alfred F. Weinberg for his paper *Age Hardening of Copper-Beryllium Alloys*; and William E. Bond for his paper *Some Properties of Silver-Copper Alloys Made by Powder Metallurgy*. Present to receive their awards were Radavich, Rainesalo, and Bond.

The President's banner for the Local Section getting the greatest percentage of new members went to the Southwestern New Mexico Section.

The New York Local Section, seasoned hosts for many an Annual Meeting, set a new precedent for fine hospitality by a cocktail party for all meeting registrants preceding the dinner-smoker on Monday night. The crowd fairly burst the walls of the Sky-Top ballroom, as good fellowship reigned. The generous contributions of mining and metal companies and manufacturers made this affair possible.

The smoker and informal dance on Monday and Tuesday nights, respectively, provided delightful entertainment and conviviality for the many reunions of registrants and their wives from all over the country. One jarring note occurred at the informal dance when, at the request of the band leader, escorts were instructed to lift their partners on high. One charming lady received a broken rib from the over-zealous performance of this pleasurable task by her partner.

In an impressive array of dinner attire, members repaired to the grand ballroom of the Waldorf for the Annual Banquet to pay their respects to the new President and award winners. With a firm but easy grace, Jerry Peirce performed his final rites as Institute President. Introducing the award winners, he presented the Robert H. Richards Award to John E. Myers; the Mathewson Gold Medal to C. G. Dunn, F. Lionetti, F. W. Daniels, and M. J. Bolton; the Robert W. Hunt Award to G. Derge, W. O. Philbrook, and Kenneth M. Goldman; the J. E. Johnson, Jr. Award to William R. Bond; the Rossiter W. Raymond Memorial Award to Donald A. Dahlstrom; and a certificate of Honorary Membership to Everette De Golyer. Following this, Mike Haider was introduced as 1952 AIME President. In a few words Mr. Haider expressed his appreciation for the honor bestowed upon him and his intention to make every effort to discharge his duties to the satisfaction of the membership.

At the close of the formal ceremonies Mr. and Mrs. Peirce and Mr. and Mrs. Haider received many hearty handshakes and congratulations. Dancing followed until 2 am.

The Metals Branch held 35 sessions; 14 by the Extractive Metallurgy Div., 14 by the Institute of Metals Div., and 7 by the Iron & Steel Div. Sessions were held on copper and lead, zinc, training of extractive metallurgists, physical chemistry of extractive metallurgy, manganese conservation, addition agents in electrometallurgy, physical chemistry and uncommon metals, uncommon metals, properties, solidification and physical metallurgy, research in progress, orientation and plasticity, a seminar on the theory of metals, crystal structure, high temperature alloys, transformation and hardening, constitutional diagrams, powder metallurgy seminar on metal ceramic materials, and symposium on oxygen in steelmaking.

Institute of Metals Div. officers pour over details of the past year and plan for 1952. At this business session, W. A. Dean took over the chairmanship of the division held by R. M. Brick.

C. S. Smith presided at one of the Research in Progress Sessions

President Peirce presents a check to student award winner Charles Rainesalo, while winners W. E. Bond and John Radevich look on

Augustus B. Kinzel, Union Carbide & Carbon Research Laboratories, Inc., presented the Howe Memorial Lecture on *Chromium Carbide in Stainless Steel*. The annual lecture of the IMD was given by William Shockley, Bell Telephone Laboratories on *Solid State Physics in Electronics and Metallurgy*. Attendance at each of the lectures was over 500.

At the Metals Branch annual dinner, Toastmaster C. C. Long, chairman of the Metals Branch Council introduced President Peirce and incoming President Hauser. The speaker, John D. Sullivan, assistant director, Battelle Memorial Institute chose as his subject *Metals' Contribution to the American Standard of Living*.

He stated that this country does not enjoy a high standard of living because we export, but because we consume, and showed how per capita consumption of many items could be used as an index of standard of living. This country has two standards of living—a basic standard measured by consumption of foods, clothing, etc., and a luxury standard. The luxury living in the U. S. can be laid to consumption of metal and other mineral products. A graph of per capita consumption of minerals and mineral products vs. time would point out the various eras, war periods, depression, etc. He attributed the high employment rate in this country to the fact that there is a large consolidation of metalworking and finishing capacity here. The manpower involved in mining or extracting almost any metal is negligible compared to the total force necessary to put the finished product on the market.

Attendance at almost all of the technical sessions, was above that expected, and standing room only was the rule rather than the exception. This was especially true of seminars and symposia sessions. Many of the papers presented, and reports on the symposia will appear in forthcoming issues of JOURNAL OF METALS.

The Woman's Auxiliary had its usual fine program of meetings and social affairs. During the registration on Monday morning a welcoming reception and coffee clatch was held under the chairmanship of Mrs. Jack Bonardi. While the men were attending the smoker, the ladies had their choice of the theatre or the opera. Tuesday morning, Mrs. Oliver Bowles, WAAIME President, presided at the Annual Meeting of the Auxiliary which was followed by luncheon and a fashion show at the Waldorf. Mrs. Felix Wormser was chairman of the luncheon and fashion show committee.

On Wednesday, the Round Table was chairmaned by Mrs. Roland D. Parks and was followed by a buffet luncheon in the Sky Top lounge, with Mrs. E. H. Robie and Mrs. H. N. Appleton co-chairmen. In the afternoon the ladies went on a tour of the United Nations headquarters.

The 173rd general meeting of AIME was the biggest ever held and its great success was made possible by the fine work of the committees of the New York Section and the Woman's Auxiliary. The work of these two groups was under the direction of Francis Cameron, chairman, New York Local Section and Mrs. D. E. Park, general chairman for WAAIME.

Mrs. L. H. Hart pours, with Mrs. N. Plummer assisting, as members await their turn at the WAAIME reception

W. McG. Peirce at the Welcoming Luncheon, shortly before introducing Judge Harold R. Medina, who spoke on "Administration of Justice."

William Shockley, center, receives the IMD Lecture scroll from R. M. Brick as A I M E President Peirce looks on.

Over 1700 persons applied for tickets to the Annual Banquet and President's Reception held at the Waldorf-Astoria Hotel. Institute awards were presented by W. McG. Peirce, and M. L. Haider took office as AIME President for 1952.

The panel of experts who led the session on Training of Extractive Metallurgists. Seated from left to right: W. O. Philbrook, A. W. Schlechten, R. Schuhmann, Jr., and B. W. Gonser. Standing: R. R. McNaughton, B. M. Larsen, J. C. Kinnear, Jr., and C. C. Long.

Seated at the head table at the Metals Branch dinner are O. C. Ralston, John D. Sullivan, C. C. Long, retiring AIME President Peirce, and R. M. Brick.

C. H. Mathewson, on the left, chats with Mathewson Award winners C. G. Dunn, F. W. Daniels, F. Lionetti and M. Bolton. Presentation was made at the formal banquet.

A. B. Kinzel, Howe Memorial Lecturer, chats with incoming President M. L. Haider, left, and T. L. Joseph, chairman of the Iron and Steel Div., right, prior to delivering his lecture.

Buehler . . .

. . . OFFERS A COMPLETE LINE OF EQUIPMENT FOR THE Metallurgical Laboratory

Buehler specimen preparation equipment is designed especially for the metallurgist, and is built with a high degree of precision and accuracy for the fast production of the finest quality of metallurgical specimens.

1. No. 1315 Press for the rapid moulding of specimen mounts, either bakelite or transparent plastic. Heating element can be raised and cooling blocks swung into position without releasing pressure on the mold.

2. No. 1211 Wet power grinder with 3/4" hp. ball bearing motor totally enclosed. Has two 12" wheels mounted on metal plates for coarse and medium grinding.

3. No. 1000 Cut-off machine is a heavy duty cutter for stock up to 3-1/2". Powered with a 3 hp. totally enclosed motor with cut-off wheel, 12" x 5/32" x 1-1/4".

4. 1505-2AB Low Speed Polisher complete with 8" balanced bronze polishing disc. Mounted to 1/4 hp. ball bearing, two speed motor, with right angle gear reduction for 161 and 246 R.P.M. spindle speeds.

5. No. 1700 New Buehler-Waisman Electro Polisher produces scratch-free specimens in a fraction of the time usually required for polishing. Speed with dependable results is obtained with both ferrous and non-ferrous samples. Simple to operate—does not require an expert technician to produce good specimens.

6. No. 1410 Hand Grinder conveniently arranged for two stage grinding with medium and fine emery paper on twin grinding surfaces. A reserve supply of 150 ft. of abrasive paper is contained in rolls and can be quickly drawn into position for use.

7. No. 1400 Emery paper disc grinder. Four grades of abrasive paper are provided for grinding on the four sides of discs, 8" in diameter. Motor 1/3 hp. with two speeds, 575 and 1150 R.P.M.

8. No. 1015 Cut-off machine for table mounting with separate unit recirculating cooling system No. 1016. Motor 1 hp. with capacity for cutting 1" stock.

THE BUEHLER LINE OF SPECIMEN PREPARATION EQUIPMENT INCLUDES . . . CUT-OFF MACHINES • SPECIMEN MOUNT PRESSES • POWER GRINDERS • EMERY PAPER GRINDERS • HAND GRINDERS • BELT SURFACERS • MECHANICAL AND ELECTRO POLISHERS • POLISHING CLOTHS • POLISHING ABRASIVES

Buehler Ltd.
A PARTNERSHIP

METALLURGICAL APPARATUS
165 WEST WACKER DRIVE, CHICAGO 1, ILL.

Personals

M. L. Haider, AIME President, has been appointed deputy coordinator of the oil producing activities of Standard Oil Co. (N. J.). Mr. Haider had been associated with Imperial Oil Ltd., an affiliated company, since 1946 when he was appointed general manager of its producing dept.

John O'Shea, retired Naval officer and formerly manager of the special products div., Thomas A. Edison, Inc., and **Ivan Sattem,** formerly associate professor of engineering, West Point, have been appointed engineering specialists to the staff of the Remington Rand Laboratory for Advanced Research, South Norwalk, Conn.

William B. MacPhee was in New York recently before leaving for Ecuador where he will be metallurgist and plant superintendent for the Ecuadorian Mining Corp., with headquarters at Quito.

LOUIS KOENIG

Louis Koenig has been named an associate director of the Southwest Research Institute, San Antonio, Texas. He had been assistant director of research at Stanford Research Institute.

George A. Landry, president, Sandia Corp. and **Donald A. Quarles,** vice-president, Bell Telephone Laboratories, have been elected vice-presidents of Western Electric Co., Inc.

Chris H. Bartlett, sales manager of Westinghouse Electric Corp.'s Sharon works, has been appointed manager of the transformer div., Sharon, Pa.

John S. Ewing has been appointed manager, stainless steel sales, U. S. Steel Co., Pittsburgh.

Steven J. Hardie has resigned as chairman of the Iron & Steel Corp. of Great Britain.

W. Frank Kelly has been appointed assistant vice-president and **John E. Holtman,** general superintendent of foundries, American Manganese Steel Div., American Brake Shoe Co.

Thomas E. Lloyd has been appointed assistant to the president of Salem-Brosius, Inc., Pittsburgh. Mr. Lloyd previously had been manager of publications for the American Institute of Mining and Metallurgical Engineers, New York, and editor of JOURNAL OF METALS.

Charles Haxby and **S. W. Galloway** have been elected vice-presidents of the Rust Engineering Co.

O. D. Rice, chief engineer, Rust Furnace Co., has been named manager of operations.

George C. Floyd, Vanadium Corp. of America, New York, has been elected a director of the company.

Harvey B. Nudelman has been appointed a research assistant in the metals dept. at Armour Research Foundation of Illinois Institute of Technology.

Keith E. Rumbel has joined the staff of Atlantic Research Corp., Alexandria, Va.

Thur Schmidt has been appointed director of research and development for the Ingersoll products div., Borg-Warner Corp., Chicago.

O. H. Gill has been named superintendent of maintenance for the Consolidated Mining & Smelting Co.

James B. Vetrano has been transferred from the analytical laboratories, Metal Hydrides, Inc., to the chemical research laboratories.

Obituaries

Thomas F. Maddick (Member 1939) died suddenly at Larkspur, Calif. on Nov. 8, 1951. He was born at Cleveland in 1888. Mr. Maddick attended colleges in England. For three years he was a machinist's apprentice for the Aber Steel Works, Swansea, England. In 1908 Mr. Maddick joined the British Metals Extraction Co. as a machinist, and in 1912 was promoted to plant foreman. Two years were spent in Sweden as master mechanic and mill superintendent and he then returned to the British Metals Extraction Co., London. From 1919 to 1921 he attended the University of Wales. After attending the University he became research engineer for the Sanguhar & Kirkconnell Collieries, Scotland. Mr. Maddick then came to the United States and joined the St. Joseph Lead Co., Bonne Terre, Mo. He joined the Anaconda Copper Mining Co., and at the time of his death was employed in the mechanical engineering dept.

NECROLOGY

Date Elected	Name	Date of Death
1940	Sam S. Coldren	Feb. 10, 1952
1915	Nelson Dickerman	Feb. 18, 1952
1939	George E. Steudel	Jan. 16, 1952

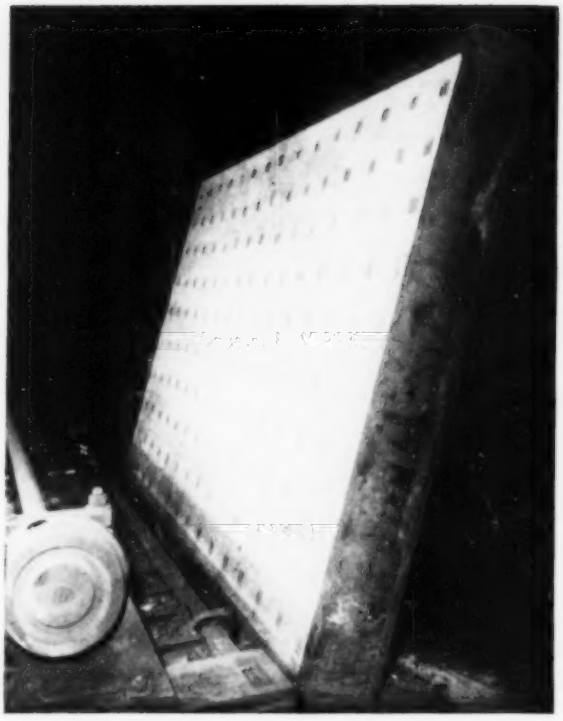
Vastly improved techniques in development of alloys are made possible by the use of alloy powders incorporating titanium and zirconium. From these base powders many true alloy powders are available in varying percentages. Among these are chromium, nickel, cobalt etc. Each particle or grain is a true alloy obviating the need of diffusion during the sintering process.

Write today — without obligation — for further technical information.

METAL HYDRIDES INC.

12-24 CONGRESS STREET • BEVERLY • MASS.

RAMTITE
SOAKING PIT COVER—
One of Many Still in Service after 3 years of operation



This Ramtite cover, a test installation, the first of eight in one plant, was put into use in a regenerative type soaking pit heating 33,000 lbs. basic open hearth steel ingots for a slab mill. The photograph was taken before firing and after five months of air drying. The combination of Ramtite cover lining and Ramtite designed slab cover frames has enabled many plants to effect considerable savings both in refractories and in the elimination of expensive hangers and sand seals.

RAMTITE STANDS FOR PROGRESS
IN PLASTIC AND CASTABLE REFRACTORIES

Ramtite specialization in designing and engineering of refractory construction has caused an ever widening recognition of Ramtite quality and reliability.

Because of Ramtite's many years in the refractory specialty business it has considerable experience which you can draw on profitably. When you are planning a job that has to do with refractories, remember that Ramtite ingenuity and engineering can help you. Unusual requirements can be met with new and fresh ideas that can mean considerable savings in time and money.

Send for complete information on Ramtite products and services.

THE RAMTITE CO.
DIVISION OF THE S. OBERMAYER CO.

1811 S. ROCKWELL ST.
CHICAGO 8, ILLINOIS

RAMTITE

PLASTIC AND CASTABLE REFRACTORIES

Proposed for Membership
— Metals Branch AIME —

Total AIME membership on Feb. 29, 1952 was 17,221; in addition 2341 Student Associates were enrolled.

ADMISSIONS COMMITTEE

T. D. Jones, Chairman, Thomas G. Moore, Vice-Chairman, Harold S. Bell, F. W. Hanson, R. H. Chadwick, T. W. Nelson, J. H. Senff, John T. Sherman. Alternates: A. C. Brooker, Ivan Given, W. A. Clark, Jr., C. A. E. Lambie, G. P. Luthen, E. A. Prentis, and C. Leslie Rice, Jr.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

In the following list C/S means change of status, R, reinstatement, M, Member, J, Junior Member, A, Associate Member, S, Student Associate.

Alabama
Birmingham—McHenry, Jr. L. Charles (J) (R, C/S—S-J)
Lusterhill—Zouraeff, Peter (J) (C/S—S-J)

California
Los Angeles—Brooker, Edgar (M) (R, J-M)

Illinois
Batavia—Gebel, Charles Rene (M)
Chicago—Carson, Jr. Neill J. (J)
Chicago—Gray, Bronis G. (M)
Forest Park—Owens, James W. (C/S—Auto A-M)
Homewood—Wilson, William G. (A)
St. Louis—Cathcart, Raymond F. (J) (C/S—S-J)

Indiana
Crown Point—Sundquist, Raymond W. (M) (C/S—J-M)
Hammond—Mahlie, Carl C. (M)
Hobart—Johnson, Fred H. (M)
East Chicago—Carban, Frederick L. (J)
Lowell—Peterson, Harold D. (M)

Maryland
Baltimore—Link, Joseph J. (M)
Baltimore—Zukor, Theodore J. (M)

Michigan
Midland—Sheptak, Nicholas (J) (C/S—S-J)

New Jersey
Fairlawn—Hill, Morse (M) (R, C/S—J-M)
Rahway—Lapat, Philip E. (J) (R, C/S—S-J)

New York
Bayside—Richardson, Franklin W. (M) (R, M)
Brooklyn—Fischer, George J. (J) (C/S—S-J)
Buffalo—Morlock, Harry A. (A)
Mount Vernon—Kerr, Charles H. (M)
New York—Burkart, Milton W. (J) (C/S—S-J)
New York—Ence, Elmars (M)
New York—Grzywacs, Wladyslaw K. (J)
New York—Jackmin, Lawrence J. (J) (C/S—S-J)
Niagara Falls—Roach, John D. (J)
Watervliet—Ciemin, Peter J. (J)

Oregon
Albany—Stephens, William W. (M) (C/S—J-M)

Ohio
Canton—Cashin, Frank M. (A)
Cleveland—Kalan, Vernon F. (M) (C/S—Auto A-M)
Columbus—Beck, Richard L. (J) (C/S—S-J)
Dayton—Anderson, Jr. Ralph V. (J) (C/S—S-J)
Mansfield—Meihack, Albert W. (M)

Pennsylvania
Allentown—Bakalar, Davis (J) (R, C/S—S-J)
Bridgeville—Klimas, Charles V. (M)
Greensburg—Sadler, Thomas H. (J) (C/S—S-J)
Johnstown—Rumrill, Edward J. (M)
Philadelphia—Sims, Wilbert N. (J)
Pittsburgh—Archer, Meyer R. (A) (R, C/S—S-A)
Pittsburgh—Lena, Adolph J. (J) (C/S—S-J)
Pittsburgh—McGeary, Robert K. (M)
Pittsburgh—Pakkala, Matti H. (M) (R, S-M)

Texas
El Paso—Lunderville, Robert E. (A)

Utah
Centerville—Hanson, Earl F. (M) (R, M)

Virginia
Roanoke—Stickley, Jr. Robert M. (M)

Washington
Spokane—Peterson, Rudolph E. (M)

Wisconsin
Milwaukee—Smith Richard C. (M) (C/S—J-M)

Australia
Victoria—Herbst, Noel F. (J) (C/S—S-J)

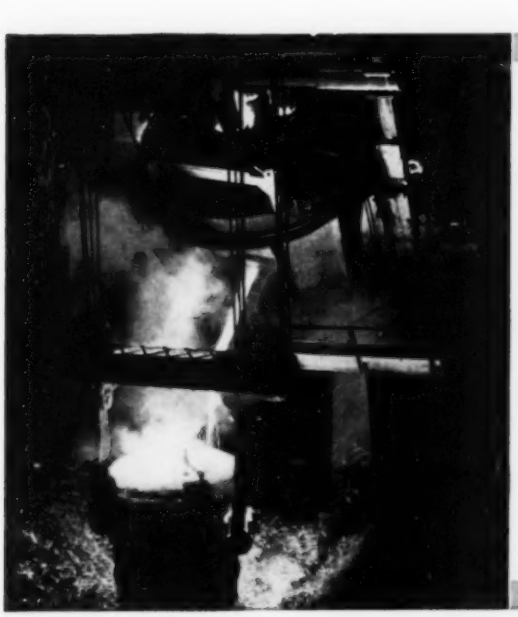
Brazil
Rio de Janeiro—deAraujo Luiz Antonio B. (J)
Sao Paulo—De Moraes, George S. (J) (R, C/S—S-J)

Canada
North Sydney—Dempsey, Patrick E. (A) (R, C/S—S-A)
Ontario—Polonis, Douglas H. (J) (C/S—S-J)
Quebec—Archer, Donald M. (J)
Quebec—McKerron, George C. (M)

England
Leeds—Foldes, Stephen (M)
Sheffield—Keen, Willie (M)

India
Bangalore—Prakash, Brahm (M)

Sweden
Stockholm—Johnson, Axel A. (M)



Heroult
ELECTRIC MELTING FURNACE

. . . as ever, the dependable furnace for the production of high-grade stainless, alloy and rimming steels.

Removable roof of new design now available for the larger furnaces.

AMERICAN BRIDGE DIVISION
UNITED STATES STEEL COMPANY
General Offices: 525 William Penn Place, Pittsburgh, Pa.
Contracting Offices in New York, Philadelphia, Chicago, San Francisco and other principal cities

USS AMERICAN BRIDGE
UNITED STATES STEEL

ROTARY SINTERING KILNS

Iron ore, manganese ore, phosphates of all sizes, flotation concentrates and flue dust alone or mixed, can be sintered regardless of moisture and carbon content.

Sintering temperature easily regulated and maintained as desired, producing sinter of proper porosity and hardness, thus saving blast furnace fuel.

Materials sintered without fines, eliminating screening and rejects.

Any available gas, oil or pulverized solid fuel may be used.

Low power consumption—7 to 8 kwh per ton of sinter.

F. L. SMIDTH & CO.

11 WEST 42ND STREET NEW YORK, N. Y.

LEWIS

4 high reversing cold strip mills

for

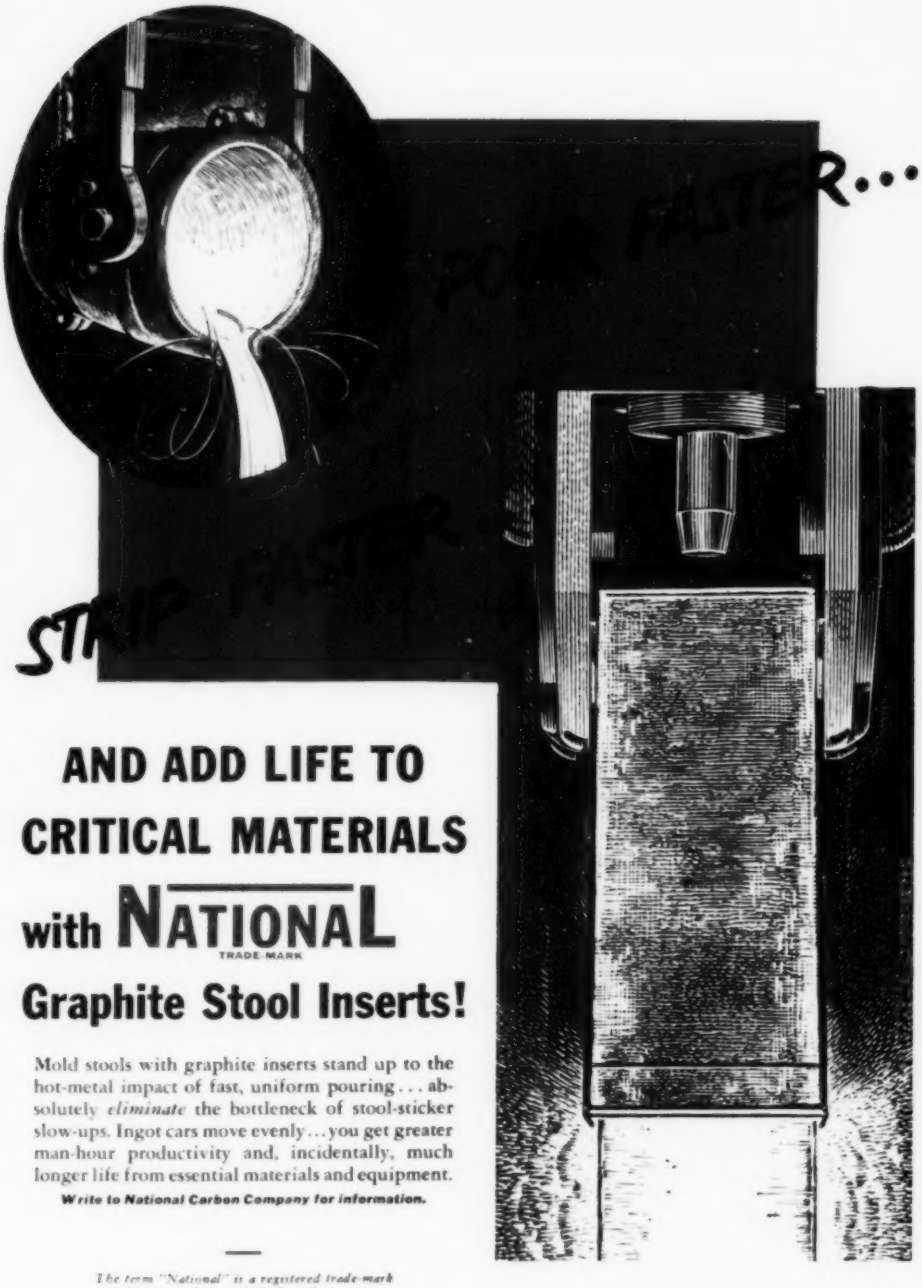
Dependable Production

MANUFACTURERS OF
ROLLS AND ROLLING MILL EQUIPMENT
FOR THE IRON, STEEL AND
NON-FERROUS
INDUSTRIES

Two 71/2" and 161/2" x 18" 4-High Reversing Cold Strip Mills. One Stand (slow speed 285/570 f.p.m.) for roughing and One Stand (high speed 570/1140 f.p.m.) for finishing. Material rolled — medium and high carbon steel 12" wide — gauges .118" to .020". Flexibility provided in this equipment to accommodate a wide range of maximum and minimum gauges.

May we have the opportunity of studying your requirements and submitting our recommendations?

LEWIS FOUNDRY & MACHINE
Division of Blaw-Knox Company
Pittsburgh, Pa.



AND ADD LIFE TO CRITICAL MATERIALS with NATIONAL TRADE-MARK Graphite Stool Inserts!

Mold stools with graphite inserts stand up to the hot-metal impact of fast, uniform pouring . . . absolutely *eliminate* the bottleneck of stool-sticker slow-ups. Ingot cars move evenly . . . you get greater man-hour productivity and, incidentally, much longer life from essential materials and equipment.

Write to National Carbon Company for information.

The term "National" is a registered trade-mark of Union Carbide and Carbon Corporation

NATIONAL CARBON COMPANY
A Division of Union Carbide and Carbon Corporation
30 East 42nd Street, New York 17, N. Y.

District Sales Offices: Atlanta, Chicago, Dallas, Kansas City, New York, Pittsburgh, San Francisco

In Canada: National Carbon Limited, Montreal, Toronto, Winnipeg